NORTH CAROLINA GEOLOGICAL AND ECONOMIC SURVEY

BULLETIN No. 28

LIMESTONES AND MARLS *of* NORTH CAROLINA

BY
G. F. LOUGHLIN, E. W. BERRY
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LETTER OF TRANSMITTAL

CHAPEL HILL, N. C., July 24, 1920.

To His Excellency, T. W. BICKETT,
Governor of North Carolina.

SIR:—There is herewith submitted for publication as Bulletin No. 28 of the Survey series of publications a report on the "Limestones and Marls of North Carolina," which has been prepared by the State Survey in coöperation with the United States Geological Survey.

With the increasing demand for lime for agricultural and building purposes, of marl for agricultural purposes, of crushed limestone and marble for concrete for buildings and roads, and of limestone for the manufacture of cement, this report should meet the many requests that are constantly being received by the Survey for information regarding these subjects.

Yours respectfully,

JOSEPH HYDE PRATT, *Director*
North Carolina Geological and Economic Survey.

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PREFACE

North Carolina as an agricultural State is intensely interested in a source of supply of lime. Since the earliest history of the state limestone in one form or another has been known to exist in eastern and western North Carolina, but no comprehensive investigation has ever been made to determine the extent and quality of these various deposits. While this state is not as fortunately supplied with limestone deposits as the adjoining states of Virginia, Tennessee, and Georgia, yet there are sufficient localities where this rock is known to occur to warrant, on account of the rapidly increasing demand for this material, that a thorough investigation of the quantity and quality of the limestone should be made. At the present time the greater proportion of the lime used in the state, both for agricultural and building purposes, is imported. This is also true of a great deal of the crushed limestone that is being used for concrete work. While it is realized, from the investigation that has been made of the limestones and marls, that it is impossible—at the present time, at least—for the state to produce and furnish the material for all the purposes for which limestone and marl are used, yet there are certain demands for this material that can and should be supplied entirely from deposits within the state. Any crushed limestone that is required for concrete work should be furnished from deposits within the state. Even though some of these deposits are in the western part of the state, freight rates should not be any greater than on shipments of similar materials from Tennessee and West Virginia.

At the present time comparatively very little building lime is made in North Carolina, and practically all of it is high calcium lime. Building lime is, however, made from both high calcium, high magnesium, and intermediate rock; and in some sections of the country a high magnesium lime is preferred to a high calcium. It is said that in eastern Pennsylvania, where large quantities of high magnesium lime are produced, high calcium lime is held in disfavor by builders, whereas the reverse is true in Virginia, where there is a large production of high calcium lime. Some of the large deposits of high magnesium limestone in this state appear to be well suited for burning into lime and to be advantageously situated as regards transportation to the principal cities of the state. The lime producer must demonstrate that his high magnesium lime can be used satisfactorily as a building lime. This use of North Carolina magnesium limestone offers an opportunity of developing into an industry of considerable importance.

What may become in the future the principal use of lime will be in chemical industries. There are at the present time more than one hundred uses of lime in manufacturing industries. The purity of the lime is the determining factor, and considerable investigation remains to be carried on before the essential properties of limes for different chemical uses are thoroughly tested and appreciated. In this field the North Carolina limestones may find a considerable use.

The use of pulverized limestone as a fertilizer or soil amendment should be very largely increased, and it is believed that both limestones in Piedmont and western North Carolina, as well as the shell marls and limestones in eastern North Carolina, can be developed commercially on a much larger scale. Both calcium and high magnesium limestone have been applied to the soil in various parts of the country with satisfactory results.

In paper manufacture both high calcium and high magnesium lime and high calcium limestone are used in the different processes; but most of them call for a high calcium lime. It is possible that some of the magnesium limestone deposits might be utilized in connection with the manufacture of paper, and also some of the higher grade limestones.

By reason of the war the supply of Austrian magnesite has been cut off, and while that country may again supply the demand for this mineral there is at present a considerable demand for dead-burned dolomite to be used for flooring and lining basic open-hearth steel furnaces and copper furnaces. Some of the high magnesium limestones of North Carolina should prove suitable for this use. Another possible use of the magnesium limestones would be in the manufacture of "basic magnesium carbonate."

Other uses for which the North Carolina limestones and marls can be developed on a still larger scale would be for chicken grit, filler for asphalt, and paint.

The presence of the splendid water powers in western and Piedmont North Carolina in the vicinity of certain of the limestone deposits offers certain attractive features for the establishment of manufacturing industries that need lime or limestone in one form or another in the manufacture of their products.

The possibility of the establishment of a cement manufacturing plant has always been of interest to the people of the state, particularly at the present time when so much cement is used in the construction of concrete roads. This question has been thoroughly investigated in connection with the investigation of the limestones of the state. As the limestone used in the manufacture of cement is finely ground, its original form is of little consequence, and may be ordinary limestone, marble, chalk, or marl. The investigation has not developed any very favorable deposits of limestone for the manufacture of cement. By far the most promising are those along the Murphy branch in Cherokee and Swain counties; near Fletcher, Henderson County; and in the vicinity of Kings Mountain, Cleveland County. It is still possible that certain of the marls and limestones of eastern North Carolina may, as they are developed, show deposits of the right quality for use in the manufacture of cement.

While at the present time the limestone industry in the state is very small as compared with the production in several of the other Southern States, yet there is an opportunity of greatly increasing its production and the value of the industry.

The present report is divided into four parts: Part I taking up a discussion of limestone and related minerals; Part II, a geological discussion and description of localities of limestone in western North Carolina; Part III, of the limestones and marls in eastern North Carolina; and Part IV, taking up a discussion of North Carolina's position in the marble, limestone, and lime industries, uses of these materials, and the future prospects of North Carolina in this industry.

The report has been prepared through the coöperation of the United States Geological Survey, and the North Carolina Geological and Economic Survey. The former detailed geologists from their staff to make the investigation. The North Carolina Department of Agriculture, through the State Chemist, made several analyses of limestones and marls, and placed at the disposal of the investigators the many analyses that they had previously made of the limestones, marls, etc., from different sections of the state.

The owners of the several limestone, marble, and marl deposits throughout the state have been very generous in permitting the investigators to visit and examine their properties, and have given them all information and statistics regarding production that were available. The State Geologist takes the opportunity here to express his appreciation and thanks to these gentlemen for the courtesies they have extended to the investigators.

JOSEPH HYDE PRATT,
State Geologist.

THE LIMESTONES AND MARLS OF NORTH CAROLINA

By G. F. Loughlin, E. W. Berry and J. A. Cushman.

INTRODUCTION

The limestones, marbles, and marls have been described in previous reports of the State Survey, the first two mainly from the standpoint of building stone resources,[1] and the last from that of general geology and agriculture[2]. As economic resources these materials have never become of very great importance, but the growing industrial importance of limestone and lime in the United States have made it desirable to bring the information on the State's resources up to date and render it readily available for future as well as present enterprises. North Carolina's consumption of lime (.02 to .03 ton per capita) is not far below the average for the United States (.04 ton per capita), but several of the limestone and marl deposits in the state are inferior in quality for certain important uses or deficient in quantity, and so far as the present industrial development of the state is concerned, the most important undeveloped deposits are rather unfortunately situated. The proximity of the important deposits to abundant undeveloped water power, however, makes them an asset of considerable value, should certain manufacturing industries be developed in the future.

The important formations containing limestone and marble in North Carolina have already been mapped and described in geologic folios of the U. S. Geological Survey,[3] and those containing marls in Volume III of the State Survey. The work of the present writers has been principally an economic study, but in order to bring all the available information together, free use with due credit has been made of the text and maps of previous writers.

The different sections of this report are arranged in the logical order for one not familiar with the character and uses of limestones and marls and who wishes to gain a general knowledge of the limestones and marls of the state. Part I aims to give only such general information as is necessary for an appreciation of the facts in subsequent parts. For

[1]Watson, T. L., and Laney, F. B., The building and ornamental stones of North Carolina, with the collaboration of G. P. Merrill: N. C. Geol. Survey Bull. No. 2, p. 283, 1906.

[2]Clark, W. B., Miller, B. L., Stephenson, L. W., Johnson, B. L., and Parker, H. N., The coastal plain deposits of North Carolina: N. C. Geol. and Econ. Survey, Vol. III, 1912. Burgess, J. L., Relation of pulverized limestone to crop production in North Carolina: N. C. Dept. of Agr. Bull. 245, 1918.

[3]Asheville Folio (No. 116), Mount Mitchell Folio (No. 124), Nantahala Folio (No. 143), Pisgah Folio (No. 147). Gaffney Folio (unpublished).

more exhaustive information reference should be made to standard text books on geology, petrology, and mineralogy. Part II deals with the limestones and dolomites, including marbles, in western North Carolina, as these are of much more present and future importance than the marls of the eastern part of the state, which are treated in Part III. Part IV considers the economic importance of North Carolina in the marble, limestone and lime industries, from the standpoint of present production and of suitability of the resources for more extensive use in different industries which require the use of limestone or lime.

PART I

LIMESTONE AND RELATED MATERIALS

Before considering the geology and economic importance of limestone in North Carolina, it is appropriate to describe for the benefit of those not familiar with the subject the composition, properties, origin, and structural features of the different materials considered in this report. For more thorough discussions the reader is referred to standard text books on geology and mineralogy.

LIMESTONE

Limestone is a sedimentary rock composed essentially of the mineral calcite or calcium carbonate which chemical formula is $CaCO_3$. It is formed by the accumulation of sediment in a body of water, particularly the ocean, but also in certain bodies of fresh water. Limestone differs from other sedimentary rocks (conglomerate sandstone and shale) in consisting almost entirely of calcium carbonate, popularly called carbonate of lime. Carbonate of lime is the principal constituent of shells and corals, and it is largely to the accumulation of these shells and corals, more or less broken and ground by the action of the waves, that limestones owe their origin. The shells themselves, thus incorporated in the rock, are known as fossils. Several different varieties of limestone owe their differences to the degree of fineness to which these shell fragments are reduced. In some rather recently formed limestones, such as the coquina, shell rock, or shell marl in the coastal region of Virginia, North Carolina, South Carolina and Florida, the shells are well preserved and the names shell rock and coquina explain themselves. Some beds of these limestones consist of fragments the size of ordinary sand grains, and others may consist of fragments as extremely fine grained as mud. As original shells range in size from several inches in length to microscopic dimensions, the fineness of grain of the limestone may be due in part to the size of the original shells as well as to the degree of grinding.

In addition to the accumulation of shell fragments, a certain amount of calcium carbonate, with which ocean water is nearly or quite saturated, may be extracted through the action of marine bacteria, and deposited by them, or may be deposited directly wherever ocean water becomes locally supersaturated, just as salt is deposited from supersaturated brine. Although saturated, ocean water contains only a very small proportion of calcium carbonate, which is only slightly soluble in water, and in some limestones the amount contributed by direct chemical precipitation or even by bacterial action may constitute a very small part. In certain localities, however, calcium carbonate derived in these ways is the principal constituent of the limestone and may form small pellets, resembling the roe of a fish, cemented together by finely crystalline calcite. Such a rock is termed oolitic limestone. Where calcium carbonate is precipitated by bacterial action in fresh water, it forms microscopic crystals. The resulting deposit resembles chalk more or less closely, and is called freshwater marl.

The fine particles of calcium carbonate, especially that precipitated by direct chemical action, may act as a cement and bind the shell fragments together. If the sea bottom subsides and the sediment already formed is buried under new accumulations, the pressure thus brought upon it tends to increase the degree of consolidation, as calcium carbonate readily readjusts itself or recrystallizes under such conditions. If the sediment becomes elevated above sea level, as have those along the southeastern coast, rainwater by dissolving small quantities of calcium carbonate from the upper layers and redepositing it in the lower layers tends further to consolidate the lower layers. Although calcium carbonate is only slightly soluble in water, it is considerably more soluble in water containing an appreciable amount of carbon dioxide. Rainwater, by extracting carbon dioxide from the atmosphere and organic acids from the decaying vegetable matter in sort, is able to exert a slow dissolving action upon calcium carbonate.

Conditions favoring the deposition of limestone must be such that little or no ordinary gravel, sand or mud accumulates with it. Conditions vary from time to time, however, even in the same place. At some times pure limestone may be deposited; at other times sand or mud with very few shells, which, when consolidated, form sandstone and shale; at still other times calcium carbonate and sand or mud may be deposited together, forming transitional rocks appropriately called sandy or arenacious limestone, limy or calcareous sandstone, shaly or argillaceous limestones, and limy or calcareous shales.

After the foregoing discussion the following terms for the designation of different varieties of limestone need little or no explanation.

Shell limestone—composed of shells, more or less reduced to fragments.

Fossiliferous limestone—in which fossil shells or other animal remains, such as bones and sharks' teeth, are prominent.

Crystalline limestone—in which the lime carbonate has accumulated largely by crystal growth around original crystalline particles in the shell fragments, or by recrystallization through the action of water and pressure. In this variety, the original character of the sediment is largely preserved.

Compact, dense, fine-grained limestone—formed of finely ground particles or from minute shells consolidated into firm rock.

Chalk—partly consolidated limestone formed essentially of microscopic shells.

Cherty or flinty limestone—containing lumps or short veins or lenses of dense silica, known as chert or flint, which result from segregation of microscopic shells or sponge spicules of silica.

MARLS

Marl is a loosely used term whose strict definition implies fine-grained, soft or partly consolidated limestone containing a considerable percentage of muddy or clayey (argillaceous) material. Shells of small to large size may be present, and in the southeastern states the name is extended to include newly formed shell rock. It is also used by many to designate "green sand," composed essentially of the mineral glauconite, a green potassium-iron silicate, with which some calcium carbonate may be present. Marl may be deposited in the ocean or in fresh water and is accordingly designated either marine marl or fresh-water marl.

DOLOMITE

Dolomite is a mineral closely related to the mineral calcite, but differs by containing magnesium as well as calcium. It is a double carbonate of these elements and is expressed by the formula $CaCO_3$, $MgCO_3$ or $CaMg(CO_3)_2$. The difference in chemical composition of theoretically pure calcite and dolomite is shown by the following analyses:[4]

	Calcite per cent	*Dolomite per cent*
Calcium oxide or lime (CaO)	56.04	30.4
Magnesium oxide or magnesia (MgO)		21.9
Carbon dioxide (CO_2)	43.96	47.7
	100.00	100.00

In many dolomites a small quantity of iron carbonate ($FeCO_3$) is also present, as shown in certain of the analyses on page 149.

Calcite and dolomite so closely resemble each other in appearance and in crystal properties that they may not be accurately distinguished without chemical or microscopic tests. When a specimen of calcite is

[4]Clarke, F. W., The data of geochemistry: U. S. Geological Survey Bull, 616, pp. 558-570, 1916.

touched with a drop of dilute hydrochloric or acetic acid a brisk foaming or effervescence results owing to the escape of carbon dioxide gas, while the calcium oxide becomes dissolved as calcium chloride or calcium acetate. Pure dolomite is affected only slightly if at all by these dilute acids. If finely ground or if treated with strong acid, dolomite also will effervesce. Where both minerals are present and very dilute acid (1 part of acid to 8 or more of water) is used, the calcite is entirely dissolved, while most of the dolomite remains with any quartz feldspar clay, fine mica, or other silicate minerals as a residue.

Rocks which consist largely or almost entirely of the mineral dolomite are also called dolomite, or dolomite rock; but in most of these rocks there is a small to varying amount of calcite, and they cannot be accurately distinguished from ordinary limestone without a chemical or microscopic test.[5] The rocks are more exactly designated dolomitic limestones. As the percentage of magnesia is an important, if not decisive, factor in the utility of the stone these rocks are frequently designated high magnesium limestones in contrast to the high calcium limestones which consist essentially of calcite. Rocks of intermediate composition are called low magnesium limestones.

The origin of rocks consisting largely of the mineral dolomite is not thoroughly understood, but study of many dolomites by different geologists has resulted in the general conclusion that, with few possible exceptions, they have been derived from limestone, part of whose calcium has been replaced by an equivalent part of magnesium before the rock had become thoroughly consolidated. The exact natural conditions, however, under which the magnesium united with the remainder of the rock and crystallized as dolomite have not been determined. Some marine shells and the hard secretions of certain plant organisms of low order called algae contain small to considerable percentages of magnesium carbonate, and account for the small quantities present in many newly formed shell limestones and coral reefs but even if a rock were formed entirely of the shells which contain most magnesia, the percentage of magnesia in the rock would be far below that of dolomite. Rocks with a considerable content of original magnesium carbonate are, however, just so much more readily changed into dolomite. The fact that marine life is continually extracting lime from sea water and that the sea water is nevertheless continually saturated with it implies that a continuous supply of lime is supplied to the ocean. This supply comes largely from the lime in river waters, and in part from the leaching of lime from

[5]Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey, Bull No. 521, pp. 24, 25, and 28; figs. 3 and 4, 1912. When calcite and dolomite are both crystallized, twinning lamellae in calcite bisect the acute angle of the cleavage rhomb, whereas those in dolomite bisect the obtuse angle.

newly deposited limestone. Although ocean water contains more magnesia than lime there is no comparable extraction of magnesia from sea water and renewal from deposits of magnesian shells. The extraction of lime, therefore, gradually increases the ratio of magnesia to lime in deposits of limestone on the sea bottom. It is also probable that renewal of the lime supply in ocean water promotes a reaction by which some of the magnesia is deposited while an equivalent quantity of lime is dissolved. These processes of leaching and replacement if long enough continued, and if aided, perhaps, by certain minor factors that need not be discussed here, bring the magnesia lime ratio to that of dolomite, that is 1:1. With this ratio established, the conditions of moist pressure at the sea bottom may effect crystallization of the double carbonate dolomite instead of a mechanical mixture of the two carbonates.

Comparison of analyses of limestones and marls in North Carolina, (pages 149 and 151) shows that in only the geologically old formations do rocks closely approach the composition of dolomite. This rule is generally applicable to limestones and dolomites throughout the earlier geologic formations, including those in North Carolina, and it is clear that even in the earlier ages certain varying factors controlled the preservation of high calcium limestone or its partial to complete replacement by dolomite.[6]

MARBLE

The term marble has been used by geologists to designate a limestone or dolomite that has become recrystallized under heat and pressure. The term in the building industry implies a relatively soft stone, partly or completely crystalline, usually composed essentially of calcite or dolomite, but including certain rocks composed of serpentine, which are adapted to ornamental building or monumental work. So many important commercial marbles do not conform to the strict geologic definition that some confusion may result unless due allowance is made for the dual meaning of the word. In North Carolina, on the other hand, most of the limestones and dolomites in the western half of the state can be called marbles in the geologic sense, but owing to excessive fracturing or unattractive color they have no commercial value as marbles, although they are adapted to various uses of limestone or dolomite.

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[6]For exhaustive discussion of the origin of dolomite see:
Steidtmann, Edward, The evolution of limestone and dolomite: Jour. Geology, vol. 19, pp. 323-345; 392-428, 1911.
Steidtmann, Edward, Origin of dolomite as disclosed by stains and other methods: Bull. Geol. Soc. America, vol. 28, pp. 431-450, 1917.
Clarke, F. W., The data of geochemistry: U. S. Geol. Survey Bull. 616, pp. 559-571, 1916.

MINOR MINERALS IN LIMESTONE, DOLOMITE, AND MARBLE

Attention has already been directed to such impurities as sand and clay in limestones. Sand in general consists of quartz grains with or without minor quantities of other mineral derived from igneous rocks, particularly feldspars (both orthoclase and plagioclase), mica and magnetite.

In some limestones silica deposited in an amorphous condition may become concentrated into flint nodules or lenses. These may develop a minutely crystalline texture and are then known as chert. Chert in turn, especially in metamorphosed limestones or marbles, becomes more coarsely crystalline and is identical with quartz. Microscopic isolated quartz grains that crystallized after deposition of the limestone have also been enlarged or entirely derived by crystallization of silica that was originally deposited in an amorphous condition.

Newly formed microscopic feldspar crystals have also been found in several limestones and dolomites, including some of those described in this report. The soda lime variety, plagioclase, is the more common, but the potash variety, orthoclase or microcline, has also been noted. Some of the feldspars, like the quartz, are clearly enlarged sand grains, but others have been entirely formed subsequent to deposition of the limestone. These newly formed feldspars are found both in unaltered limestones and in the recrystallized or marbleized varieties like those of North Carolina.

Mica, like feldspar and quartz, may be represented by original and secondary grains, but, owing to the ready deformation and minute sizes of the grains in most limestones, it is difficult to determine their mode of origin.

Pyrite (iron disulphide) is commonly present in minute grains, which constitute only a small fraction of 1 per cent of the limestone. Locally, however, it is rather abundant, and ruins the stone for several uses. Its origin in such small quantities is obscure, but may be attributed to reduction of iron sulphate to sulphide by the decaying organic matter derived from marine life. In some rather recently found limestones, like those of the Coast Plain, iron disulphide may be present as the mineral marcasite, which readily oxidizes on exposure to the weather; but in the older limestones of the Piedmont and mountain regions it is present as pyrite. Pyrite also oxidizes after more prolonged exposure, especially where both water and oxygen can attack it, and in many of the limestones described in Part II it is partly or wholly changed to the hydrated oxide, limonite.

During the recrystallization of limestone or dolomite into marble, the impurities present may combine with the lime or magnesia and crystallize into a number of silicate minerals of which the following are the more common in North Carolina:

Tremolite, a white to gray silicate of magnesia and lime.
Actinolite, a green silicate of magnesia, iron, and lime, with or without some iron.
Talc, white to gray hydrous silicate of magnesia.
Serpentine, a green hydrous silicate of magnesia.
Epidote, a green hydrous silicate of lime, alumina, and iron.

At or near contacts with intrusive igneous rocks these and other minerals in metamorphosed limestones may owe part of their constituents to material which emanated from the intrusive rock and invaded the limestone for a varying distance.

One specimen of high calcium limestone from Hewitts, Swain County, when dissolved, left a residue containing considerable fluorite (calcium fluoride). The origin of this mineral or the source of the fluorine in it is not clear, but fluorite is generally regarded as a secondary mineral.

LIME

Lime, calcium oxide, is the residue left after burning limestone at a temperature of about 900° C. or 1652° F. to drive off carbon dioxide. The chemical reaction is as follows:

Limestone or Calcium Carbonate		*Carbon Dioxide*		*Lime or Calcium Oxide*
$CaCO_3$	=	CO_2	+	CaO

The term lime in commerce includes the residue left by the burning of dolomite or magnesian limestones, which is a mixture of lime (calcium oxide) and magnesia (magnesium oxide). The chemical composition of lime is designated as high calcium lime, low magnesium lime, or high magnesium lime, whose ranges in composition are as follows:[7]

	Percentage of magnesia
High calcium lime	0 to 5
Low magnesium lime	5 to 25
High magnesium or dolomitic lime	25 to 45

High calcium lime is made from stone containing more than 93 per cent calcium carbonate; low magnesium lime from stone containing 7 to 27 per cent magnesium carbonate; high magnesium or dolomitic lime

[7] Emley, W. E., Source, manufacture, and use of lime: Mineral Resources of United States, 1913, Part II, p. 1556, 1914 U. S. Geological Survey.

from stone ranging from 27 per cent to a theoretical maximum of 45.7 per cent magnesium carbonate, although a small amount of this is replaced by iron carbonate.

The importance of lime in chemical industries and agriculture is due to the readiness with which it enters into a number of chemical reactions and to its cheapness. In the building industry its usefulness is due to its ready combination with water to form slaked or hydrated lime according to the reaction.

Lime		*Water*		*Hydrated Lime*
CaO	+	H^2O	=	$Ca\ O^2H^2$

Magnesia under certain conditions also forms a similar union with water, but this reaction does not take place in magnesian lime as ordinarily burned and slaked. The proportion of water necessary to slake lime, therefore, depends upon the amount of magnesia present, an important point in the use of lime.

Hydrated lime, when exposed to the air, gradually exchanges its water for carbon dioxide, which it extracts from the air, according to the reaction.

Hydrated Lime		*Carbon Dioxide*		*Calcium Carbonate*		*Water Vapor*
$Ca\ O^2H^2$	+	CO^2	=	$Ca\ CO^3$	+	H^2O

This reaction, called the setting of lime, results in the return of the lime to the form of carbonate, the chemical state in which it originally existed. As this change is accompanied by considerable shrinkage proper quantities of sand, hair or other fiber are added to prevent cracking.[8]

Texture of Limestones—The term texture refers to the size and arrangement of the constituent particles of a rock. A rock may be fine, medium or coarse grained. If the grains are of microscopic size the rock is commonly called dense; but the word has also been applied to well compacted rocks of relatively coarse grain. The term microgranular, though cumbersome, is less confusing. The distinction between these degrees of granularity is necessarily arbitrary.

Texture is also influenced by the degree of consolidation. Recently formed deposits of marl are of soft earthy texture; the partly consolidated deposits of shell rock are loose textured or friable. Both are porous, finely porous if the pores or interstices among grains are invisible,

[8]A thorough discussion of the burning, slaking, and setting of lime would cover several pages. For a general discussion the reader is referred to Emley, W. E., The manufacture of lime: Bureau of Standards Technical Paper No. 16, 1913; also Mineral Resources of the United States, 1913, pp. 1556-1593. Special subjects are discussed in the transactions of the National Lime Manufacturers, and in Rock Products.

coarsely porous if they are readily noticed. Rocks composed of fragments of shells or corals, or fragments derived from the erosion of other rocks have fragmental textures, whereas those whose grains are welded together by crystallization have crystalline textures. If the fragments or crystals show little or no variation in size, the rock is even grained, otherwise uneven grained. In some rocks of uneven grain, crystals or grains of relatively large size are scattered through a groundmass of uniform grains, and the texture resembles the porphyritic texture of granite and other igneous rocks. The term porphyritic is best restricted to igneous rocks, however, and the texture in question may be called porphyroid or pseudoporphyritic.[9] All or nearly all these textural features may be present in a single rock; thus, the shell rocks of the Coastal Plain are a coarse or fine, even or uneven grained, fragmental, porous, friable rocks. The limestones in the Piedmont and Mountain regions are coarse or fine, even or uneven grained, crystalline, non-porous, well compacted rocks.

There is no sharp textural difference between limestone and marble, as all gradations may be found from partly consolidated material to thoroughly crystalline rocks that take an excellent polish. Granular crystalline limestones which lack this distinctive property of marble contain small empty interstices or consist largely of minute irregular grains of untwinned calcite, some of which may preserve the organic structure of original shell fragments, whereas marble is free from such interstices and consists of more uniformly crystalline interlocking grains.[10]

Structure of the Limestone.—The term structure applies to features of a rock mass or formation as a whole rather than to its constituent particles. It includes original features, as well as those developed subsequent to the rock's formation. Original structures are mainly features of bedding. If a limestone were deposited under conditions which remained uniform for a long time, so that little or no variation in bedding or stratification is apparent it has a massive structure; if lines of bedding are visible several feet apart, it is thick bedded; if alternations in conditions of depositon took place, so that layers or strata from a few inches to 1 or 2 feet thick are separated by material of different character or by planes of weakness, the rock is thin bedded. In many thin-bedded limestones the planes of weakness or parting contain very thin layers or mere films of shaley or clayey material, showing that deposition of limestone had ceased temporarily and that a small quantity of

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[9]An excellent illustration of this texture is given by T. N. Dale (Lime-producing belt of Mass. and Conn.: Bull. U. S. Geol. Survey to be published in 1920 or 1921.)

[10]Dale, T. N., The commercial marbles of western Vermont: U. S. Geol. Survey Bull. 521, pp. 11-12, 1912.

mud or clay deposited in its stead, these conditions alternating during the formation of the entire rock. Where the movement of waves or currents varied, sometimes permitting deposition of fine and sometimes of coarse material, the resulting rock is well stratified in contrast to the massive rock. If the direction of currents shifted, eroding channels which later became filled with sediment, the newly formed layers bevelling the eroded ends of older layers, the resulting rock is cross bedded. If changes during deposition are marked by layers of different color, the rock has a banded structure.

These original structures are quite as important as textures in determining the commercial value of a limestone. The most promising marbles of the state owe their commercial qualities mainly to thick-bedded or massive structures, accompanied by attractive banding. Cross bedding is not conspicuous in these rocks, although it is present in some of the shell rocks of the Coastal Plain and is an attractive feature in such famous rocks as the marble of eastern Tennessee and the limestone of the Bedford-Bloomington district, Indiana. Thin bedding and abundance of shaley partings may ruin a stone for building purposes and lime burning, and in extreme cases even for crushing.

Secondary structures are mainly due to forces of compression or strain within the earth, which have acted upon rock masses and deformed them to a greater or less degree. The most prominent structures in the rocks of western North Carolina are due to forces acting in a generally horizontal direction, which have so compressed them that they have a series of folds or arches and depressions technically called anticlines and synclines. The beds of limestone which originally lay nearly horizontal, as those in the Coastal Plain do today, now lie at various angles to the horizontal. Throughout the Appalachian region the thrust of these forces was so great in a northwestward direction that in many places the folds were overturned in that direction and were even broken, the eastward part of the fold being overthrust upon the western part for considerable distances. In some places, however, as the northern limestone area in McDowell County, the overthrust was eastward, and in a few places, as at Woodlawn and Hot Springs, it was nearly circular, thrusting rocks from all directions upon a central mass. The planes along which this overthrusting took place are called overthrust faults, the term fault applying to any fracture or fissure along which movement has taken place, so that portions of a stratum or bed of rock on opposite walls are no longer in alignment.

During such tremendous deformation, fissuring or jointing was also developed, the degree of fissuring depending largely upon the character of the rock. Rocks composed mainly of calcite can adjust themselves more readily than the other common rocks by recrystallizing under slowly applied, heavy pressure. While recrystallizing under this condition the rock acts like a plastic body and flows, or readjusts itself, without fracturing. Pressure more quickly applied, however, will produce fractures. Dolomite possesses this property to a less degree, and where beds of rock composed essentially of calcite alternate with dolomitic beds, the calcitic beds may be free from serious fracturing, but the dolomitic beds so intensely fractured as to be useless for marble or building stone (see fig. 1). It is significant that the only successfully developed marble quarry in the state is in high calcium, or calcite marble.

Fracturing to a greater or less degree also took place at times subsequent to the period of intense folding and overthrusting, due to less intense compression, to expansion of the rocks upon relief of compression, and to vertical uplift. Vertical uplift which has brought the coast plain deposits above sea level without appreciably tilting them is the only major force that has acted upon the marls and shell rock in the eastern part of the state. These formations have doubtless developed joints through contraction which accompanied the gradual and partial loss of water.[11]

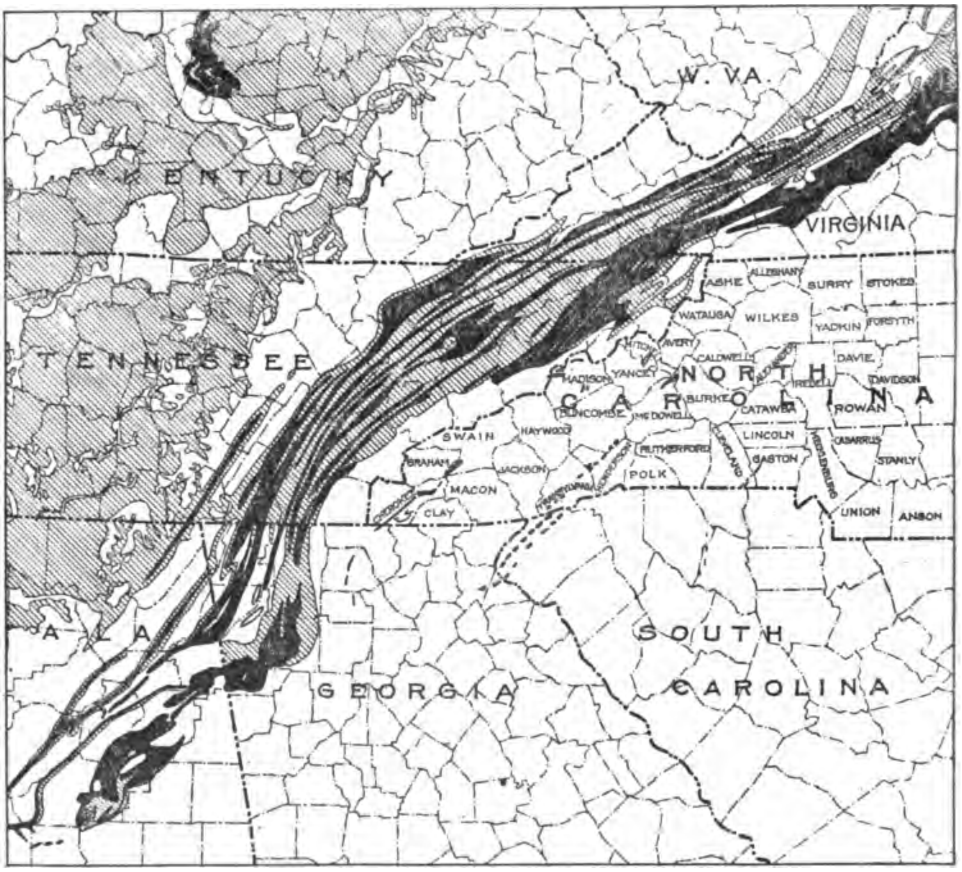
Weathering of Limestones—The latest natural process that has affected and still is affecting the limestones of North Carolina is that of erosion, which has reduced them to their present forms. Calcite, although only slightly soluble in pure water, is more soluble in rainwater containing a small quantity of carbonic acid, and very appreciably soluble in water that has become acid after passing through and leaching the decaying vegetable matter in soils. Dolomite is less readily soluble than calcite under these varying conditions, but both minerals are much more quickly dissolved than quartz and the silicate minerals which are the main constituents of the rocks associated with the limestones and dolomites of North Carolina. If the rocks are much fractured or contain many open bedding plains or partings they can be much more rapidly permeated and attacked by the acid waters. Changes in temperature by causing rocks to expand and contract repeatedly, weaken the cohesion of the grains, and widen small fractures or joints, permitting the access of films of water and further hasten the dissolving process. The freezing of these films of water in winter also tends to pry the grains and rock fragments apart. The particles thus loosened, as well as any grains of quartz, feldspar, mica, or other minerals that may be present

[11]For further discussion of the structural geology of North Carolina, the reader is referred to the folios Nos. 116, 124, 143, and 147 of the Geologic Atlas of the United States, by Arthur Keith, U. S. Geological Survey.

in limestone, are washed into streams and rivers, rapidly where slopes are steep, but with extreme slowness where they are nearly horizontal. On steep slopes, therefore, bare rocks may be continually exposed to weathering until the slopes have been greatly reduced. In gently sloping areas, the rock may be dissolved or decomposed faster than the loosened grain can be worn away, and a residual soil accumulates. The residual soil over limestones consists only of the insoluble impurities that were in the limestone supplemented by the insoluble remains of rocks that formerly overlay the limestone. It contains no calcium carbonate or lime capable of counteracting the acidity of soils and is as much in need of agricultural lime as are other soils.

The process of weathering in limestone continues down to slightly below the level of permanent ground water level. Below this level the acidity of the water has become exhausted. Where limestones are exposed in areas above the valley bottoms, the residual soil may be seen to extend downward for a short distance and to be followed by a series of limestone pinnacles separated by soil-filled chasms, frequently called mud seams. These chasms are enlarged fractures whose walls have been dissolved away by groundwater. They taper downward and at or slightly below groundwater level pass into ordinary fractures or joints. Mud seams are present in marl quarries as well as in those of hard limestone. In valley bottoms, where ground water level is very close to the surface, the pinnacles have been dissolved away and the mantle of residual soil rests directly upon a continuous flat surface of limestone.

The processes of weathering continued through thousands and even millions of years have brought about the present forms of mountains. Where an arched or tilted bed of limestone between masses of less readily weathered rock has been worn away a depression or valley has resulted, as illustrated by the limestone formations in Cherokee and Swain Counties (Pl. II), in Lincoln and Cleveland Counties (Pl. IX), and by the dolomitic limestone in McDowell County (Pl. VII). The development of these and other valleys had not progressed to completion, and it is where portions of the limestone still remain along the slopes of these valleys that the best quarry sites are to be found. Only a very small percentage of the total limestone area in the state affords the best quarry sites. Other sites are available in broad flat valley bottoms, but the stone lies mostly, if not wholly, below ground water level, and the quantity of water that must be pumped may be a critical factor in determining the successful operation of a quarry.



Map showing position of North Carolina with respect to Limestone Resources in the Southeastern States

PART II

LIMESTONE IN WESTERN NORTH CAROLINA

INTRODUCTION

The limestones of the Piedmont Plateau and the Appalachian Mountains are found in Buncombe, Cherokee, Clay, Cleveland, Henderson, Transylvania, Macon, Madison, Mitchell, Gaston, Catawba, Jackson, Lincoln, McDowell, Yadkin, Swain, and Stokes Counties. According to the accompanying map (Pl. I), these limestones in part form elongate areas of considerable size, and in part linear groups of comparatively small lenses. Most of these areas (all except that at Hot Springs) lie along valleys and are so thoroughly concealed beneath soil that their limits have been determined only by very detailed surveys. The local geologic maps in this report, all of which are copies of published or unpublished maps of the U. S. Geological Survey, thus indicate considerable areas of concealed limestone, although only a few scattered exposures are present.

GEOLOGIC DISTRIBUTION

These areas include several different formations ranging in age from Archaen, the oldest recognized age in the earth's history, to late Cambrian, which though the latest age represented in North Carolina is the earliest of those whose geologic history has been very definitely recorded. The most extensive limestones of the country belong to several ages which successively follow the Cambrian and are represented in the neighboring States of Virginia, West Virginia, Tennessee, Georgia, and Alabama.

The following are most of the recognized geologic formations in North Carolina as correlated by Arthur Keith. The oldest formation is at the bottom, with those containing limestone especially designated:

CORRELATION TABLE OF FORMATIONS IN PARTS OF WESTERN NORTH CAROLINA

Geologic Age	Nantahala Quadrangle (Cherokee, Macon, Clay, and Swain Counties)		Asheville Quadrangle (Madison County)		Mount Mitchell Quadrangle (Mitchell and McDowell Counties)		Pisgah Quadrangle (Buncombe, Henderson and Transylvania Counties)		Gaffney Quadrangle (Lincoln and Cleveland Counties)	
	Geologic Formation	Thickness (Feet)	Geologic Formation	Thickness (Feet)	Geologic Formation	Thickness (Feet)	Geologic Formation	Thickness (Feet)	Geologic Formation	Thickness (Feet)
Ordovician			Athens shale Knoxdolomite	300+ 3,500+						
	(Sequence broken)		Nolichucky shale	450 to 500						
	Nottely quartsite	150	Honaker limestone	100+						
			Watauga shale	600+						
	Andrews schist	200 to 350	*Shady limestone*	800 to 950	Shady marble	600+			Gaffney marble	30 to 300
	Murphy marble	150 to 500	(Marble)							
	Valleytown formation	900 to 1,200	Hesse quartsite	700 to 1,200	Erwin quartsite	600+				
Cambrian	Brasstown schist	1,200 to 1,500	Murray slate	300 to 450	Hampton shale					
	Tusquitee quartsite	20 to 500	Nebo quartsite	350 to 1,700						
	Nantahala slate	1,400 to 1,800	Nichols slate	750 to 2,100						

	Great Smoky conglomerate..........	5,500 to 6,000	Cochran or Great Smoky conglomerate..........	300 to 2,500	(Sequence broken)				Blacksburg schist........	800 to 1,000
	Hiwassee slate (No limestone)	500	Hiwassee slate, with *limestone* lentils.	900 to 1,500	Brevard schist (No limestone)	1,000+	Brevard schist, with limestone lentils.	800		
	(Sequence broken)		Snowbird formation (sequence broken).....	350 to 5,000					Quartzite, conglomerate and schist	
Archaen.......	Granite, soapstone, dunite and serpentine		Granite, soapstone, dunite and serpentine		Granite, soapstone, dunite and serpentine		Granite, soapstone, dunite and serpentine		Granite, soapstone, dunite and serpentine	
	Roan gneiss Carolina gneiss (no limestone)		Roan gneiss Carolina gneiss, with limestone lentils		Roan gneiss Carolina gneiss, with limestone lentils		Roan gneiss Carolina gneiss (no limestone)		Roan gneiss Carolina gneiss, with limestone lentils	

The fact that masses of the Shady limestone and its approximate equivalent, the Murphy marble, are present in widely separated counties, shows that they are the uneroded remnants of extensive formations that were once continuous over a great part of the present mountain region. The other limestones were also doubtless once more extensive than their present metamorphosed remnants, but probably are not continuous. The most extensive limestone formations of the Appalachian region include the Shady limestone, Knox dolomite, and several formations younger than the Athens shale, which probably once extended over western North Carolina, but have been entirely removed by erosion.

Although other facts of scientific interest may be deduced from the foregoing table there is little of practical importance to be gained from it, so far as economic geology of limestones is concerned. In some regions differences in chemical composition of the limestones of different ages may render distinction of their respective ages of considerable importance. In North Carolina, however, high calcium and high magnesium beds, the latter predominating, are present in each limestone formation, and as the structure in each area is complicated and more or less obscure, it is not safe to predict the kind of limestone that will be found at any locality. Each quarry site requires careful prospecting. For this reason the limestones will be considered in geographic rather than geologic order.

GEOGRAPHIC DISTRIBUTION

Cherokee, Clay, Macon, and Swain Counties

GENERAL DESCRIPTION OF THE MURPHY MARBLES AND ADJACENT ROCKS

The most extensive of the limestone and marble formations in the state is that designated the Murphy marble (Pl. II), which forms a narrow band extending northeastward almost continuously from Georgia along the valleys of Nottely and Valley rivers for nearly the entire length of Cherokee County. After an interruption of a few miles it reappears along the valley of Nantahala River in Swain County from Nantahala to Hewitts, where it pinches out. It is named from Murphy, county seat of Cherokee County, which is partly situated along its most continuous area. It also forms a group of narrow areas in the vicinity of Brasstown and Peachtree, east of Murphy, in Clay County.

The following description is given by Keith:[12]

Character—The formation consists entirely of marble, rather fine grained and wholly recrystallized from its original condition. The predominant color is white. A large portion of the marble is of a dark-gray or blue color and

[12]Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Nantahala folio, No. 143, p. 5, 1907.

many layers consist of banded or mottled blue and white. Some of the layers between Nantahala and Red Marble Gap have a beautiful rose-pink color. The amount of this is limited, however. Except these variations in color and small changes in the coarseness of the grain, the formation is very uniform in this region. The base of the marble is almost always covered in this region, and the precise character of its contact with the underlying rocks can be seen only near Nantahala River. There it passes downward into the Valleytown formation by interbedding with the slates of the latter. Upward it passes into the Andrews schist through several feet of interbedded marble and schist. This transition can best be seen at Marble Creek, at the western border of the quadrangle. * * * In various analyses of the marble its composition varies from 58 to 93 per cent of carbonate of calcium and from 36 to 3 per cent of carbonate of magnesium. Accordingly the original strata included both limestone and dolomite.

Thickness—Such measurements of the formation as can be obtained place the thickness at nearly 500 feet. The best measurements are southwest of Tomotla, where the formation stands nearly on edge and so continues for a long distance toward the southwest. Between Marble and Valleytown the marble spreads out over large areas. This is caused in part by the flattening of the dips and in part by the extreme crumpling and repetition of the layers. Instances of both attitudes of the marble beds can be seen in various quarries and openings. Along Nantahala River the formation thins down to about 150 feet.

Alteration.—Originally the marble consisted mainly of massive layers of limestone and dolomite, with the latter more frequent in the lower portion of the formation. With its base were interbedded argillaceous shales and with its top calcareous shales. During the metamorphism of the formations the carbonates of lime and magnesia were recrystallized with no considerable change of form. The argillaceous materials were for the most part transformed into various micas and other silicates forming the schists. Still other silicates were developed through the mass of the rock, such as tremolite and garnet; their formation involved the addition of silica to the materials already in the rock. They are disseminated through the formation rather sparingly and also are concentrated into definite beds of the marble. The tremolite appears crystallized in radiating bunches, with no apparent relation to the schistosity of the adjoining rocks. It seems probable, therefore, that it was of later formation than the other minerals. Tremolite also appears crystallized in the same manner in the talc bodies which are found in the marble. Garnet is of much less frequent occurrence than the tremolite and is found in only a few places in the lower parts of the formation. The same layers which contain the garnet also carry pyrite in small grains. This mineral is found in disseminated grains in other layers as well.

In the upper layers of the formation, where the marble passes into the Andrews schist, many crystals of ottrelite are scattered through the beds of marble. This mineral is characteristic of the overlying schist. Besides the alternating beds of marble and schist near the contact, there is present nearly every gradation between the ottrelite-schist and the pure marble. The ottrelite crystals are arranged with their cleavage at right angles to the general schistosity of the rock wherever that is present.

Other deposits ocurring in the marble are layers of talc, the hydrous silicate of magnesia, which are mined throughout their course in this state and in Georgia. These appear at frequent intervals near Nantahala and Valley rivers. In the southern areas of the formation, on Peachtree and Brasstown creeks, no talc deposits have thus far been discovered. The principal development is in the vicinity of Hewitts on Nantahala River. Near Marble they also become prominent and appear at frequent intervals toward the southwest. The talc occurs in the form of lenticular bodies embedded in the marble. They are from a few inches up to 6 or 8 feet in thickness and the largest are over 100 feet long. Few attain that size, however. They appear to be of a secondary nature and have been produced during the metamorphism of the formations. Small bits and flakes of talc are found at many places, but they are too lenticular in shape and distinct from the marble. The lenses of talc are not confined to any one situation in the marble, but appear at several distinct levels. In association with the talc deposits are often seen beds of calcareous sandstone. These have no definite relation to the talc, however, and are not always present.

Owing to the highly soluble nature of the Murphy marble its course is always marked by valleys. Where the formation spreads out along the upper part of Valley River it has caused the series of broad valley bottoms which have given the river its name. Outcrops of the marble are scarce and are seldom found away from the sharp stream cuts or the steep slopes. In the bottom lands near Andrews and those along Peachtree Creek the marble may be found at almost any point by digging through the few feet of stream gravels which form the surface. As a consequence of this solubility it has no soils of its own, and those which overlie its areas consist almost entirely of materials washed in from other formations. The rock itself when found is not affected to any depth by the weather.

The Valleytown formation, which underlies the marble, consists mainly of mica-schist and fine-banded gneiss, but in the Nantahala valley these pass into mica-slate and feldspathic sandstone. The Andrews schist, which overlies the marble, is a thin-bedded calcareous rock spangled by crystals of the black micaceous mineral ottrelite whose flakes lie at right angles to the foliation. The Andrews schist, which has largely weathered to soil, forms small terraces 10 to 30 feet in height above the marble areas. This formation is absent in Nantahala valley and the Nottely quartzite, which overlies it, is there found forming the upper contact of the marble for part of its extent. Elsewhere a profound fault has brought up the Nantahala slate to form the southeast boundary of the marble. These structural relations are shown in (Pl. II).

ADAPTABILITY

Monumental and Building Stone.—The adaptability of the stone for use as marble has been discussed by Keith[13] and by Watson and

[13] Op. cit. p. 7.

Laney[14], to whose reports the reader is referred for detailed discussion. Their general comments may be summarized as follows:

Marble has two principal colors, white and blue. The blue stone is for the most part mottled or banded with white. What is probably the largest body of white marble is in the bottom lands of Valley River below Andrews. An exceptional color and one of great beauty is the rose pink exposed just north of Topton (Red Gap). The grain of the marble is for the most part uniform and medium to fine and does not appear to be changed by transition from one color band to another. Thin layers of micaceous minerals where present cause a slight schistosity, but do not seriously affect the strength or quarrying of the rock. Near both its contacts the marble is very impure, containing tremolite, talc, and in some places considerable quartz. Away from the contact it is very free from most impurities, although it does contain more or less pyrite.

The objectionable feature to the marble as a whole is the abundance of joints, or fractures. According to Laney[15] there are everywhere two systems of joints that trend N. 20°—35° E. and N. 30°—70°W. respectively, and in which the joints are from one inch to a few feet apart. Besides these two systems there is in most places a third and in some a fourth system of subordinate joints.

The thickness of soil overburden in general is from 4 to 15 feet.

Although several quarries have been opened in this marble area, only one has been continuously operated. The main features of some of these quarries will be considered on pages 36-43.

Other Uses.—The presence of both high calcium and high magnesium stone, as shown is analyses Nos. 1 to 15 on page 149, implies that material is available for most or all of the industries requiring lime in any form, and the fact that only small quantities of stone have been shipped for others uses than marble is largely due to remoteness of the marble area from industrial centers and sources of fuel supply. Of the 15 analyses, Nos. 1 and 15 represent high calcium rock low enough in silica to make excellent flux. There is little doubt that much of the waste rock at the Regal quarry is also excellent for this use. Nos. 6, 7, 11 and 12 represent high magnesium stone low enough in silica to be used as flux. The fact that only 6 of 15 analyses show silica within the requirement (2 per cent) signifies the necessity of care in the selection of stone for flux.

[14]Watson, T. L. and Laney, F. B., Building and ornamental stones of North Carolina: North Carolina Geological Survey Bull. 2, pp. 192-200, 1906.
[15]Op. cit. p. 198.

3

The qualities of stone from different parts of the area for road building are shown in the first six tests recorded on page 149. Three of these are somewhat below the average for the limestones of the State. Dolomite from Hewitts shows the best results as regards per cent and coefficient of wear, and has a relatively high cementing value, though its hardness and toughness are comparatively low.

Five of the 15 analyses on page 149 show a magnesia content low enough to meet the requirements for Portland cement. Further thorough prospecting is necessary, however, to prove the presence of high calcium rock free from interbedded dolomite and in sufficient readily available quantity to furnish a continuous supply to a modern cement plant.

All the analyses except No. 14 show that the stone in general is of suitable chemical composition for the manufacture of lime for building purposes, but attempts to burn lime have shown that some of the rock, notably a high calcium stone at Hewitts, discolored during burning. The burned lime would doubtless be suitable for several chemical uses, but for certain uses the percentage of "insoluble," or of silica, alumina, and iron oxides, and of magnesia are with few exceptions too high.

LOCAL DESCRIPTIONS

SOUTHWEST OF MURPHY

Southwestward from Murphy the marble forms a narrow band along Nottely River, outcropping at very few places, and for the most part concealed beneath the narrow low flats bordering the river, where drainage conditions are prohibitive for the opening of quarries. Perhaps the most prominent exposure is at the Kinsey quarry, close by Kinsey station on the Louisville and Nashville Railroad. This quarry was opened in 1901 and was described by Laney[16] in 1906, as an excavation about 100 feet by 80 feet in area and about 50 feet deep, partly filled with water. This description still applies, as little or no quarrying has been done since that date, although some stone, presumably the blocks of discarded marble mentioned by Laney have been sold for furnace flux.

The marble here has the usual steep southeastward dip, and the quarrying followed a bed, now concealed beneath water, as far as the railroad's right of way. The footwall is strongly slickensided. The stone was described by Laney as rather coarsely crystalline and mostly of dark blue gray color more or less mottled or streaked with white, although much of it was light gray and a few blocks showed a pinkish tinge. The general character of the stone was so similar to that at Regal, northeast of Murphy, that no samples were taken for analyses.

[16]Watson, T. L. and Laney, F. B., op. cit. pp. 194-195.

Joints were so numerous that it was impossible to get enough solid stone to warrant operating the quarry for marble. The overburden was 8 to 12 feet thick. The character and structure of the stone were apparently satisfactory for production of flux and crushed stone, although the silica or insoluble content (analyses 2, 3 and 4, page 149), was a little high, but the quantity above water level was not sufficient to warrant much outlay of capital for quarry equipment.

Just south of Kinsey station on the southeast side of the track is another old quarry, in which only two small exposures remain unconcealed by the washing down of red clay soil from the overburden. These exposures are of fine grained but well crystallized dolomite of pure white color except for occasional short faint dark colored lines, evidently due to finely divided graphite. A qualitative analysis shows the presence of a small amount of iron carbonate but an almost entire absence of insoluble matter. Those exposures are very well situated as regards transportation, but considerable development work is necessary to re-expose the quarry face and determine the thickness of workable stone and of overburden in the surrounding heavily wooded area. The exposures are too much jointed to give promise as marble, but the stone is well adapted for chemical uses which require high magnesium stone free from silica.

About one-half mile southwest of Kinsey marble of rather fine grain and dirty white color is exposed in a small railroad cut but contains so much tremolite, talc, and quartz in short veinlets and irregular patches, and pyrite in disseminated grains, that it is not adapted for any use except perhaps inferior crushed stone, and rip rap, and it is too far from any market to be considered for these.

An abandoned quarry opened in 1901 or 1902 at Culberson near the Georgia boundary was described by Laney.[17] The quarry, close by a small stream was full of water and no stone could be seen in place. Soil overburden was at least 4 to 7 feet thick. Piles of marble blocks, rendered worthless by abundant intersecting joints, lay around the opening and showed the stone to be of rather uniform medium grain and of dark to light streaked or mottled bluish gray. This description, like those of the openings at Kinsey, suggest that the stone is suitable for flux and other chemical uses, provided it can be economically quarried; but there is practically no likelihood of finding a favorable quarry site between Kinsey and the Georgia boundary. An analysis of the rock is given in column 1, page 149.

About one-half way between Kinsey and Murphy Nottely River bends northward and leaves the marble band, which extends northeastward

[17]Op. cit. p. 193-194.

along a minor valley and crosses a low divide 300 feet above the level of the river. It is possible that self-draining openings could be made in this part of the marble formation, but the stone is so thoroughly concealed, even in this high ground, that no idea of the amount of stripping and character of the stone can be learned without development work.

NORTHEAST OF MURPHY

Regal Marble Co.—From Murphy northeastward nearly to Tomotla the marble continues as a straight narrow band, almost entirely concealed beneath soil, but containing the only active marble quarry in the State. This is the quarry of the Regal Marble Company, at Regal Station, three and one-half miles northeast of Murphy. The quarry was described by Laney[18] in 1906, when it was operated by the National Marble Company.

This quarry was opened in 1902 and when visited by Laney had hardly passed the exploratory stage. A small production was made in 1903 and 1904, but none in the following 3 years. In 1907 the quarry was taken over by the Casparis Marble Co., which produced steadily until 1913, when it was succeeded by the Regal Marble Co., which has produced steadily up to the present time.

In 1918 the total quarried area was more than 250 feet long and about 75 feet wide. The northern two-thirds of the area had been abandoned and filled with water to within 25 feet of the surface. Pumping, quarrying, and milling machinery were operated by steam power. The quarry equipment included 4 derricks, 4 chennelers, and 2 gadders; the mill equipment 7 gangue saws.

According to Laney the marble band here has a width of about 300 yards, the beds striking N 45° E and dipping about 50° SE. The stone seen in the quarry, mill, and dump is prevailingly dark bluish gray, in part more or less streaked or mottled with white, and light gray to white. It is on the whole rather coarse grained and has on close examination a rather distinct schistose structure.

The dark bluish gray variety is seen on close inspection to consist of blending bands of dark and medium shade, the former of coarser grain and predominating to such an extent that small blocks of uniform dark shade may be obtained. Small rod-shaped crystals of tremolite up to one-quarter of an inch in length and small grains of pyrite are very thinly scattered. In thin section the schistose structure is more pronounced, and one section showed a few short sealed fractures in two systems at 30° and 60° respectively with the plane schistosity. Members of a single fracture system were two or more millimeters apart.

[18] Watson, T. L., and Laney, F. B., op. cit. p. 195.

The prominent elongate calcite grains are mostly one millimeter or less in length, though a few attain lengths of two millimeters, and practically all grains show multiple twinning in one or two directions. The pyrite grains seen in thin section were one-half millimeter in diameter and free from oxidation. The dark coloring matter was collected as an insoluble residue and proved to be graphite. It mostly forms wavy rows of specks along the boundaries between calcite grains, but a few calcite grains are somewhat impregnated with it. Examination of the insoluble residue of a dark gray specimen found no other impurity besides graphite, and a qualitative test showed the soluble part of the rock to be free from iron.

A prominently banded specimen proved to consist of light gray layers one-half to three-quarters inch thick, separated by a one-inch thickness of alternating white and dark gray strips, each one-sixteenth to one-quarter inch thick. Many such variations in detail may be found between the dark variety described in the last paragraph and the light gray. Occasional small crystals of amphibole, presumably tremolite coated with graphite, are present in the dark layers, and one green rod-shaped crystal of actinolite, nearly an inch long, was found in a white layer. This was the largest crystal of any impurity noted in the salable stock or the waste pile, although impurities in greater quantity are present along both margins of the deposit. In a thin section of the banded variety the marked schistose structure is confined to the dark, graphitic layers, in which few calcite grains exceed a length of one-quarter millimeter. The light gray layers are composed of larger irregular but for the most part rounded grains, the more prominent averaging one millimeter in diameter. The larger grains inclose, or partly inclose, several small round grains, most of them less than one-quarter millimeter in diameter, which are probably dolomite. Both the large and small grains show close multiple twinning.

The light gray to white variety conforms on the whole to the description of the light gray layers just given. Examination of the very small insoluble residue of nearly pure white specimen showed a few minute grains of quartz and talc, but a qualitative test of the soluble portion shows no iron, though considerable magnesia. The light gray stone seen by Laney was on the whole fine grained and schistose, but this variety was not conspicuous in 1918. The fine grained stone was said to be injured to a considerable extent by shearing strains which developed planes of weakness along the schistosity and fractures in transverse directions, rendering the stone worthless for marble. Laney's statement that these defects are characteristic of the fine grained light colored stone of the whole marble area is confirmed by the writer who adds that the fine grained light colored stone so far as tested is very dolomitic. The tendency of dolomite to fracture while calcite marble recrystallizes without injury is a characteristic of other marble regions as well.

A conspicuous feature, shown by several blocks both in the stock piles and the dumps, is the presence of short contorted veins of white calcite lying transverse to the bed planes of the marble. The simpler contortions are S-shaped and the more complex are irregular or distorted repetitions of the simpler forms, (see fig. 1). These veins were evidently formed prior to the intense folding and compression of the formation and their present contorted shapes are attributed to drag folding; that

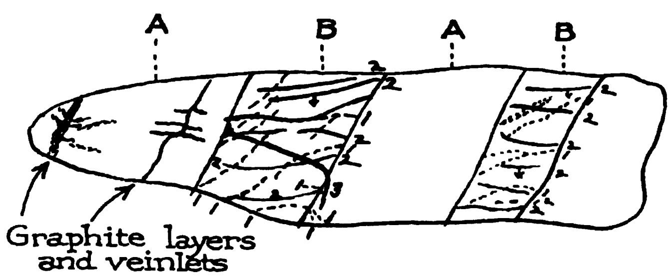


FIGURE 1.—Alternating beds of (*a*) relatively coarse grained calcitic and (*b*) relatively fine grained dolomitic marble; the former free from evidence of deformation other than gneissic structure and a few short graphitic veinlets branching from graphitic bed planes; the latter cut by (1) short white veinlets of calcite, (2) short cracks produced by compression accompanied by only a little shearing, and (3) F-shaped fractures produced mainly by shearing. Dump of Regal Marble Co., Regal, N. C.

is the sliding of one layer of marble over another accompanied by recrystallization of both the marble and the vein. The process was decidedly complicated in detail, some thin layers moving relatively in one direction while layers on both sides of them moved in the opposite direction. So far as observed, these contorted veins are more numerous in the dark colored marble, which also is the more schistose. It is therefore reasonable to infer that the greater tendency of the dark beds to slide over one another was due to the relative abundance of graphite in them. Some of these may add to and others detract from the appearance of the stone, but, owing to the thorough recrystallization during the process of deformation, do not detract from its strength or durability.

The same process served to ruin stone where beds of calcite marble alternated with finer grained beds containing considerable dolomite, as the dolomitic beds recrystallized less readily and were more readily fractured. On the dump one block which contained two dolomitic layers in which the prominent dolomite grains were mostly less than one-fifth of a millimeter in diameter, showed three stages of deformation in the dolomitic layers, (fig. 2): first, a series of short cracks oblique to the bedding and filled with white calcite veinlets which may have formed at the same time as the contorted veins described in the preceding paragraph; second, short somewhat curved cracks unfilled and nearly normal to the sides of the bed, evidently formed by a compressive stress which tended to thin and spread individual layers, the calcitic layers recrystallizing and developing a gneissic structure while the dolomitic layers yielded to some extent by recrystallizing and to some extent by fracturing; third, a shearing stress, probably following as a continuation of the compressive stress, that caused the beds to slide or flow over one

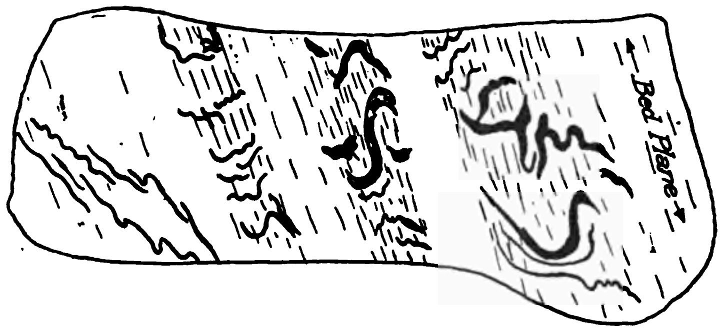


FIGURE 2.—Diagramatic sketch showing the more prominent contorted white calcite veins in dark gray banded marble. Dump of Regal Marble Co., Regal, N. C.

another, the calcitic beds yielding as before by recyrstallization and the dolomitic beds by oblique *f*-shaped fractures which cut obliquely across the veinlets and fractures of the first and second stages and end at or just beyond the margins of the calcitic beds.

Jointing or fracturing on a large scale is prominent and closely spaced. In the openings studied by Laney[19] there were three distinct sets of joints, the more prominent trending N 40° W and N 20° E. Joints in these sets ranged from a few inches to a few feet apart, usually two to six feet. The third set was subordinate but caused considerable waste in quarrying. In the present opening joints are less conspicuous. There are few solution channels or mud seams and small caves, and these are mostly confined to the upper four or five channel levels, which aggregate about 20 feet in thickness, though one small cave is exposed at the bottom of the pit, 20 feet lower. The walls of these upper levels show many short, irregular fractures branching from the prominent joints, which extend below the bottom of the quarry. Some of the prominent joints dip about parallel to the beds (50°-60° SE) and others

[19]Op. cit. p. 196.

about 40° SE, while another set dips about 50° NW. The strikes of these joints could not be seen, but doubtless conform to the directions noted by Laney. Besides these comparatively straight joints, there are a few irregular fractures ranging from 1 or 2 to 50 feet or more in length. Some of these dip northeastward, others westward at low angles, and still others are nearly horizontal. Water seeps along joints of all these systems, and water level in the abandoned pits is about 20 feet below the surface.

The different periods of deformation to which the marble has been subjected may be summarized as follows: (1) fracturing and the filling of fractures with calcite veins previous to the period of metamorphism; (2) folding or tilting and metamorphism, including recrystallization, with development of schistose structure and differential sliding or flowing of beds over one another, contorting the veins and producing local compression and shear fractures in the more dolomitic beds; (3) overthrust faulting, which was virtually a late stage of the folding period and was accompanied by accessory jointing in different directions; (4) one or more later periods of jointing; (5) minor fractures near the surface due to temperature changes; (6) enlargement of joints and minor fractures into erosion channels or mud seams by circulating water. The local evidence is insufficient for the exact correlation of different systems of joints with the third and fourth periods. The positions of all the joints noted are such that they could be tenatively correlated as fractures accessory to the great overthrusts of the region, but later earth movements may well have been responsible for some of them.

The foregoing description is given in detail to serve as an example of the difficulties that must be contended with in the opening of quarries in this marble belt. Although joints at the Regal quarry are so close as to obstruct seriously the extraction of blocks large enough for monolithic columns, blocks large enough for sawing into sizes suitable for ordinary monumental work are readily obtained; but from 65 to 70 per cent of the stone removed is waste, owing principally to fracturing and in minor part to contorted veinlets. The stock sold is mostly in small sizes. Before the war it paid to work up all small pieces that could sell at slightly more than cost, but owing to the present high cost of operation much of the smallest sized stock cannot be handled. The output is shipped for monumental use to various states, a considerable quantity having gone to California.

About 75,000 tons of waste rock were on the dump in 1918. Some waste had been sold to the Tennessee Copper Mining Company, presumably for flux, but present high freight rates have destroyed this market. General freedom from silica and iron (the pyrite present is practically negligible) adapts the stone, either crude or burned, for certain industrial and chemical uses in which small to moderate quantities of magnesia are not objectionable. The dark gray variety appears on the whole to have only a very small content of magnesia, whereas the light gray variety, especially if fine grained, may be rather high in magnesia. The dark stone will yield burned lime suitable for building, agriculture, and many chemical uses, as well as the manufacture or refining of sugar, paper (soda process), tanning, and other calling for a very pure high calcium lime; the unburned stone is suitable for flux, crushed stone, pulverized stone for agriculture, and other uses in which the dark color is not objectionable. The light gray stone should also yield good burned lime for building, agriculture, and certain chemical and industrial uses.

Tomotla-Andrews Area.—From Tomotla northeastward to Andrews and Valleytown the marble belt is considerably wider than to the southwest, and from Marble northeastward it averages about three-quarters of a mile in width. Its area is marked by a broad valley only a few feet above drainage level and the stone is beneath 5 to 20 feet of soil and any quarrying would involve considerable pumping and the piling up rather than dumping of waste. Small outcrops principally in stream beds that cross the area and stone from prospects near Tomotla and Marble stations are similar in color, texture, and occurrence to the varieties at Regal.[20] The only chemical analyses available (Nos. 6-7, page 149) are of high magnesium or dolomitic rock, from the J. T. Hays property near Tomotla and the C. N. Hickerson place, 1½ miles west of Andrews; but there is little doubt that high calcium rock is also present. The dip of the marble near Marble station is about 40° SE, and its greater width is due to folding and perhaps faulting which cannot be adequately studied from the few data available.

The largest exposure in the whole area, a ledge 30 feet long, 20 feet wide, and rising 5 feet above the surrounding soil is found at the eastern edge of Andrews on the bank of the Valley River. It is described in detail by Laney.[21] The stone here is considerably coarser grained and less schistose than at any of the places to the southwest. The colors are light to dark bluish-gray, uniform in some places and mottled or streaked in others. The microscopic features are similar to those of the stone at Regal, although schistosity is less prominent. Jointing, grouped in two systems, N. 20° E. and N. 70° W. is much less abundant than at places previously mentioned. Other outcrops in the vicinity of Andrews and northeastward to where the marble pinches out are small and much fractured.

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[20] Watson, T. L., and Laney, F. B., op. cit. p. 197.
[21] Idem, pp. 197-198.

Fine-grained dolomitic marble of white, bluish gray, and mottled colors has been prospected by several drill holes at the Hickerson place across the river from Andrews Station and has been reported to be sufficiently free from fractures to be considered for building purposes.[22] It is represented by analysis No. 12, page 149. Pratt[23] believes it probable that the stone represented by this analysis lies near a contact with a talc lens or with quartzite, since according to his observations all the marble in the proximity of such contacts is of a dolomitic character. Laney[24] describes the dark bluish gray rock as similar in every respect to the stone described in the preceding paragraph, and that several drill cores 5 to 7 feet long and entirely free from joints were obtained.

All things considered, the broad valley area east and southwest of Andrews is a promising place for the development of a marble quarry. The colors of the stone, however, bring it into direct competition with the marbles of Regal and Tate, Ga., to the south, and of Maryland, New York, and Vermont to the north; and the abundance of jointing, so far as indicated, is a disadvantage when compared with the great scarcity of joints at Tate and their relative scarcity at other districts. The high freight rates said to prevail on the Murphy Branch of the Southern Railway may be a further disadvantage, but these are not so serious for marble as for lower priced products, such as flux, crushed stone, and burned lime. Pumping may also become a serious factor, but is successfully cared for in similarly situated quarries, both of marble and of limestone in North Carolina and elsewhere. The only satisfactory method of locating a good quarry site in this area is systematic core drilling until an area of good appearing stone relatively free from joints and impurities can be found that is extensive and thick enough to justify the necessarily large outlay of capital for development work.

CLAY COUNTY

Peachtree Creek Area, Clay County.—The marble deposits represented on Plate II along Peachtree Creek and near Brasstown in western Clay County and the adjacent part of Cherokee County, is a part of the Murphy marble and conforms to it in general description. They have been reported to be sufficiently free from defects to warrant careful consideration by prospective marble producers, but Laney's examinations in the district show the rock wherever exposed to be too much fractured and too impure for marble quarrying. It presumably is adapted, where

[22] Lewis, J. V., Notes on building and ornamental stone: N. C. Geol. Survey, 1st biennial report, p. 99, 1893.
[23] Pratt, J. H., The mining industry in North Carolina during 1901: N. C. Geol. Survey Economic Paper No. 6, p. 80, 1902.
[24] Op. cit., p. 198.

impurities are few or absent, to the same range of chemical uses as the stone in the main area to the northwest but is too far from the railroad to be of present commercial importance.

MACON COUNTY

Red Marble Gap, Macon County.—Northeast of Andrews and Valleytown the Murphy marble is largely eliminated by an overthrust fault (Pl. II, section A-A). A small lens is exposed, however, near Red Marble Gap northeast of Topton. According to Merrill,[25] who obtained the information from Professor Kerr, former State Geologist:

"The rock is a beautiful light flesh pink, sometimes blotched or striped with blue and yellow. The texture is fine and it acquires an excellent surface to polish. The stone is stated by Prof. Kerr to occur in the side of the mountain in cliffs 150 feet or more in height, and blocks of almost any size can be obtained. It is quite different from anything now in the market and would doubtless find a ready sale if once introduced."

Although this information has been available for several years, no development work has been recorded.

Ellijay Creek, Macon County.—The only other known deposits of limestone or marble in Macon County are those mentioned in the following quoted paragraph.[26]

"In Macon County, near the headwaters of Ellijay Creek, near Cullowhee Gap, limestone has been burned to lime for building and fertilizing purposes on the property of John Bryson. About one-half mile west of the gap is the Haskett lime quarry that was worked quite extensively some years ago."

Four partial analyses of samples collected by Professor Kerr in 1879 or earlier are as follows:[27]

Calcium carbonate	72.01	62.51	71.56	66.86
Magnesium Carbonate	7.82	9.76	9.18	3.78
	79.83	72.27	80.74	70.64

It is not known to what geologic formation these deposits belong. It appears probable from their geographic position that they may be lenses in the Carolina gneiss or in the Brevard schist. Nothing is known regarding their chemical composition, and they are too remote from railroad lines to be of commercial importance.

SWAIN COUNTY

North Carolina Talc and Mining Co., Swain County.—Farther northeastward along the Murphy Branch marble forms a continuous area from a mile south of Natahala station to a point three-fourths of a mile

[25] Merrill, G. P., Stones for building and decoration, p. 221, 1903.
[26] Watson, T. L., and Laney, F. B., op. cit., pp. 208-209.
[27] Annual report of the North Carolina Agricultural Experiment Station for 1879: The Observer, Raleigh, N. C., 1879.

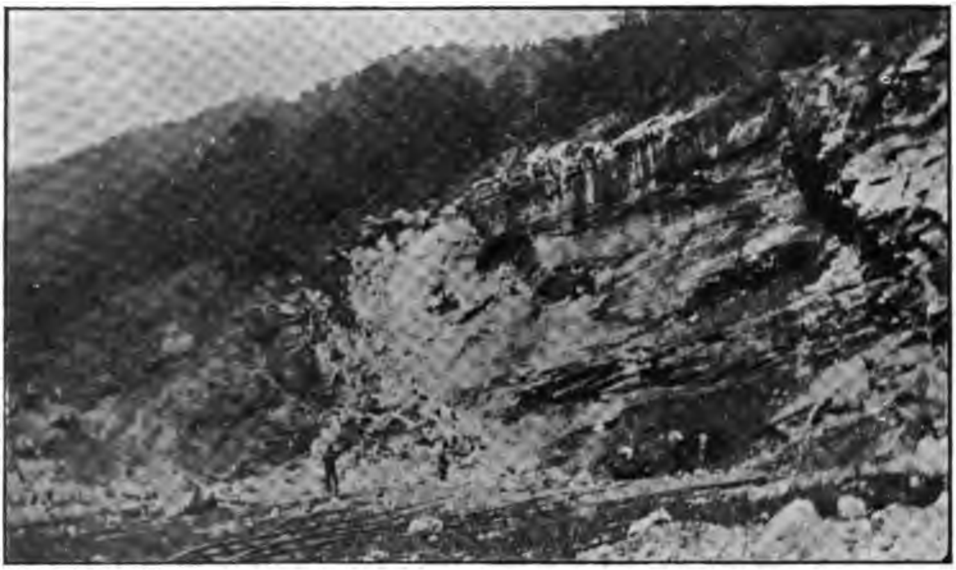
northeast of Hewitts station. All of this area is now owned by the North Carolina Talc and Mining Co. This company has produced talc for several years and has shipped crushed stone and burned lime in nearly every year since 1912; but in 1918 the increased cost of operation, together with the shortage and poor quality of fuel and labor due to war conditions, prevented successful operation. Development work on marble prospects took place as early as 1902. In 1910 the present owners took out some splendid blocks near Hewitts station for exhibition at the Appalachian Exposition in Knoxville, Tenn.,[28] but no further production has been reported.

The marble in this area crops out on the west slope, well above the level of Natahala River, and quarries can be made self draining, a decided advantage compared with the quarries and prospects in Cherokee County. The stone, however, is likely to be more cut by mud seams and caves than that in the low flat areas. Water power also can be developed on a larger scale, and the fact that shipments of crushed stone and lime have been profitably made in normal times is evidence that freight rates, though high, are not prohibitive. (See Plates III and IV).

The stone for the most part is different in color and texture from that to the southwest in Cherokee County. The principal colors, as stated by Laney,[29] are light gray to nearly black and cream white to pink, in some places uniform and in others in alternating bands and patches. Some of the pinkish rock has greenish streaks and is attractive in rough blocks but does not take a smooth or polished surface. The combinations of color are not usual among domestic marbles. Except at one or two places the weathered stone has so highly developed a schistose or platy structure that it breaks into thin plates or into narrow blocks resembling sticks of cord wood. These defects may disappear, however, with increasing distance below the surface where strains due to changes of temperature are less.

The most promising locality in the area for marble quarrying is the prospects already developed, which lie about half a mile southwest of Hewitts station and 300 to 400 feet above the railroad. The platy structure here is distinct but less highly developed than elsewhere, and Laney has suggested that marketable slabs can be obtained by sawing blocks parallel to the schistosity. Two drill records furnished by Mr. F. R. Hewitt, president and treasurer of the company, and quoted by Laney[30] are repeated here.

[28]Pratt, J. H., and Berry, H. M., The mining industry in North Carolina in 1908, 1909, and 1910: N. C. Geol. & Econ. Survey, Economic Paper No. 23, p. 114, 1911.
[29]Watson, T. L., and Laney, F. B., op. cit., pp. 200-202.
[30]Idem, p. 201.



A. Hewitt Limestone Quarry, Hewitt, Swain County

B. Outcrop of limestone, Hewitt, Swain County

One hole at the prospect just mentioned showed:

1.	Bluish gray, mottled and banded with white	20 feet
2.	Purplish pink, color not uniform, more or less green interbanded	12 feet
3.	Pink with more or less green, green increasing with depth	30 feet

This hole penetrated only the upper part of the formation, which at this place is reported to be about 600 feet thick.[31]

A second hole drilled in a ledge of "black" magnesium marble near the north end of the company's tramway showed:

1.	Bluish gray	20 or 30 feet
2.	Pink with some green streaks	8 or 10 feet
3.	Purplish pink, mottled with green	20 feet
4.	Cream white	7 or 10 feet

A third hole bored for talc just north of Hewitts station passed through 250 feet of the marble at an angle of 35° to the horizontal or about normal to the dip. Before the adjoining properties were purchased by the present company borings had been made at several points, from the railroad siding known as Talc Mountain on the north to the southwest end of the area, but no records of them were saved.

Stone for crushing and lime burning has been quarried at three places connected by a tramway with the lime kiln and the crusher, both of which are along a railroad siding. The southern and smaller quarry, at the south end of the tramway, consists of medium to dark bluish gray high calcium stone, of uniform appearance as a whole but with fine black bedding lines conspicuous in places. The dip here is about 60° southeastward. The exposed rock contains several small caves with mud-stained or rust-stained walls. Some of the caves contain stalactites. The black lines are more conspicuous on exposed than on freshly broken surfaces. The stone is of medium to fine grain and in thin section presents a very marked schistose character, the more conspicuous grains averaging one-half millimeter or less in length and less than one-quarter millimeter in thickness. The black lines, here as elsewhere in the Murphy marble belt, are due to obscure microscopic wavy rows of minute particles of graphite. Small grains of pyrite averaging about one-fiftieth millimeter in diameter are thinly but evenly scattered. Quartz, constituting less than 1 per cent of the section, is also rather evenly scattered in grains with average diameter one-twenty-fifth millimeter, and a few grains of sericite and plagioclase are also present. Fluorite (calcium fluoride) though subordinate to quartz is conspicuous in the insoluble residue.

[31]Written communication by Mr. F. R. Hewitt, May 12, 1919.

Qualitative chemical tests confirm the microscopic evidence and also disclose a small, but distinctly greater than ordinary content of iron in the soluble portion of the rock.

Beds between the two quarries, both in areal position and stratigraphic relations, are exposed along the tramway. They contain many small pits where talc lenses have been worked.

The larger quarry, at the lime kiln and just south of the station, has a face about 40 feet high beneath a soil overburden which varies from 1 or 2 to 5 feet in thickness. The beds dip 35° SE. The upper half of the rock exposed consists of a bed about 20 feet thick of light bluish gray rather fine grained dolomite, mostly of even color, but with occasional thin bands or fine black lines and thinly scattered patches of white coarse grained dolomite. It is cut in places by many short sealed fractures, some of which when broken open are spotted by brown rust. The weathered surface is light brown, soft, and sandy. In thin section this rock is uneven grained, grains with average diameter of less than one-tenth millimeter being grouped around twinned grains whose diameters range up to one-half millimeter in diameter. Insoluble minerals are practically absent. Qualitative chemical test shows a small but distinctly greater content of iron than in the stone at Regal.

This bed is underlain by ten feet of light gray rock, fine grained with coarse grained patches and streaks much cut up by slickensided fractures lined with talc and by many short white dolomitic veinlets. Short brown stained streaks are also present, some of them bordering the white dolomite veinlets. Thin sections show the presence of several minute pyrite grains, and suggest that the brown streaks are due to oxidation of iron contained in the dolomite of the veinlets. The talc forms wavy lines in part accompanied by distinctly schistose dolomite and here and there offset or deflected by microscopic faults and contortions. Insoluble minerals other than talc are practically absent. Solution of this rock in rather strong hydrochloric acid leaves a residue of talc and the filtrate yields a considerable precipitate of iron hydrate, evidently derived in part from the brown streaks and greenish coloring matter of the talc, but mainly from the dolomite. Below this bed is dolomite similar to the upper bed in appearance, but harder and more shattered and cut in places by talc seams.

The stone in this quarry, while much too shattered to be considered for marble quarrying, has been shipped as crushed stone and burned to lime for use in the preparation of wood pulp (sulphite process) for paper making. The upper 20 feet are suited for flux, crushed and pulverized stone, and for any chemical uses requiring high magnesian lime-

A. Hewitt Limestone Quarry, Hewitt, Swain County

B. First quarry opened. Blue limestone. 20 feet above railway track.—G. C. Buquo Lime Company, Hot Springs, N. C.

stone or lime low in silica and alumina but not free from iron. The middle ten-foot bed appears unsuited for lime burning because of its structure and content of talc. Its impurity also bars it from chemical and metallurgical uses whose requirements are exacting. For crushing it may give moderate satisfaction, but lacks the uniformity and degree of hardness and toughness and the bonding surface possessed by the overlying bed for concrete or for road metal; as pulverized stone it can serve the small neighboring markets, but is hardly pure enough to command a wider market in competition with limestones and dolomites of higher grade.

North of the station the limestone area is honeycombed with pits, trenches and short tunnels from which talc has been mined. The stone debris around these workings contains a considerable quantity of impurities, including talc, tremolite, black micaceous minerals, quartz seams, rusty specks derived by oxidation of pyrite. Pure stone is also present but the difficulty of separating it from the impure stone is discouraging so far as cheap quarrying is concerned.

Mr. Hewitt[32] states that the dolomite from the quarry at the lime kiln burns to an excellent grade of high magnesium lime, averaging about 54 per cent calcium oxide and 42 per cent magnesium oxide. For three years it supplied the demand of the Champion Fibre Company at Canton, until owing to a change in process high magnesium lime was no longer needed. He states that the high calcium rock burns to lime that contains 96 to 98 per cent calcium oxide but is likely to burn to various colors—some white, some red and sandy and some dark gray to black. He has found no satisfactory explanation of this discoloration. Although the coloring bars it from uses where a white color only is required, the lime has been sold by dealers to various points in the South.

The discoloration of the high calcium rock during burning, however, is not objectionable to the stone's use in the manufacture of Portland cement. The company's property is well situated with respect to raw materials, water power, and railroad facilities, and is the most promising prospect in the state for a plant of this kind. It is necessary, however, to prove that high calcium rock exists in sufficiently large quantities free from interbedded layers of dolomite. The distance from markets and fuel supply has also been a drawback to the establishment of a Portland cement plant in this part of the state.

[32]Written communication.

Madison County

The limestones (including marbles) of Madison County belong to the following three formations named in order of geologic age; small lenses in the Carolina gneiss, larger lenticular beds in the Hiwassee slate, and the Shady limestone. The Shady limestone in the vicinity of Hot Springs is the only one of more than local interest.

LENSES IN CAROLINA GNEISS.

The Carolina gneiss covers an extensive area in Buncombe County but extends only six or seven miles northward into Madison County in the vicinity of French Broad River. It consists of interbedded light and dark gray gneisses and mica schists, and, particularly in Madison County, of thin layers of hornblende schist, which marks its transition into the closely associated Roan gneiss. The inclosed lenses of crystalline limestone are found only in the vicinity of Marshall (Pl. V), and are described by Keith.[33]

Associated with the gneiss, but forming an unusual exception to it in character, is a group of marble beds. Two of these are found in Marshall and five are 2 miles west and northwest of Marshall, four of these lying in a nearly straight line southward from French Broad River. Outcrops of the marble are found only in or near the streams, on account of the soluble nature of the rock. At first they seem to be different outcrops of a continuous bed, but it is doubtful if this is the case, because at a few intervening points the marble is plainly absent. It is probable, therefore, that the marble deposits are of lenticular shape. Considerable differences in thickness can be observed, even in the small exposures near the streams, but these may be due to the extreme folding that all of the rocks of the region have undergone. The maximum thickness observed was on Walnut Creek northwest of Marshall, where the outcropping beds are 60 feet thick, with a possibility of as much more concealed. About 200 feet farther north the entire section was occupied by gneisses. South of French Broad River the thicknesses observed range from 10 to 35 feet. The thicknesses shown in Marshall have about the same variations.

The marble is fine grained and is usually white. It contains 84 per cent of carbonate of calcium, 2 per cent of carbonate of magnesium, and 13 per cent of silica. Many portions have a somewhat greenish color, due to tremolite, which forms many small prisms and stubby crystals. Other variations of color are due to small knots of epidote, tremolite, and calcite, and to lenses of fine quartz and hornblende. These seem to be in the nature of secondary segregations and are of frequent occurrence throughout all the marble beds. The most important variation in the marble is seen in the series of thin lenses and sheets of silica that it contains. These are seldom over 2 inches in

[33] Keith, Arthur, U. S. Geol. Survey. Geological Atlas, Asheville folio (No. 116), p. 2, 1904.

thickness and are composed of extremely fine-grained quartz. They appear to represent original sedimentary bands, replaced by silica, and have been extremely contorted and folded, like the adjoining gneisses. The value of the marble for building stone is much injured by these various impurities. A few seams of mica-schist found in the marble contain the same minerals and are metamorphosed to the same degree as the adjoining Carolina gneiss. There is, therefore, little doubt that the marbles are of substantially the same age as the gneiss. The gneiss is cut by Cranberry granite at many points within a few feet of the marble, but the granite does not touch the marble at any point. The presence of these marble beds makes it probable that at least part of the Carolina gneiss is of sedimentary origin.

A chemical analysis of one of these lenses is given in column 17, page 150. Recasting into mineral components shows 74.70 per cent calcium carbonate (instead of 85 per cent quoted above) and 2.27 per cent magnesium carbonate. These are equivalent to 72 per cent calcite and 4.97 per cent dolomite. There remains an excess of 5.54 per cent lime, most of which is accounted for by tremolite, hornblende, and epidote, though a small quantity may be present with the soda in small untwinned grains of plagioclase (lime-soda feldspar) not readily distinguishable from quartz under the microscope. The potash is probably present in inconspicuous grains of orthoclase (potash feldspar) or sericite (a potash mica). The iron is mostly present in epidote.

Although some of these lenses appear on the map to be well situated for quarrying, the description of the stone and the chemical analyses give little encouragement for development. Its high content of silica condemns it for lime burning, or pulverized limestone or other chemical uses of limestone, and renders it harder to work as marble than the well known marbles of the country which contain very little silica. The presence of tremolite and hornblende (silicates of magnesia and lime with more or less iron), epidote (silicate of lime, iron, and alumina), may supply a variegated appearence to parts of the stone. The tremolite particularly, however, is likely to weather out on prolonged exposure, leaving a pitted surface, as are the streaks of mica schist.

LENTICULAR BEDS IN HIWASSEE SLATE.

The rocks in this formation occupy two large irregular areas north-northeast of Hot Springs and a third area west of Hot Springs and mostly across the Tennessee boundary (see Pl. V). The name of the formation is derived from Hiwassee River in Polk County, Tenn. The formation consists almost entirely of bluish gray or bluish black slate which weathers to greenish, yellowish gray, and yellow. In the areas north-northeast of Hot Springs many of the beds are somewhat sandy. All three areas are characterized by a series of interstratified lenticular limestone beds. According to Keith.[34]

The largest single body mentioned by Keith[35] is that on Little Laurel Creek just south of Allen Stand, where the thickness is over 100 feet and the length over 4 miles. He also states that the limestone bodies are all more or less siliceous, but are sufficiently pure to furnish material for local needs.

SHADY LIMESTONE.

There are two parallel areas of this formation in the vicinity of Hot Springs in North Carolina and others to the northwest in Tennessee. It is named for its occurrence in Shady Valley, Johnstown County, Tenn. The following paragraph is an abstract of a general description by Keith.[36]

The formation consists almost entirely of fine grained limestone and dolomite of various kinds, more or less crystalline, and near Hot Springs is nearly 1,000 feet thick. The prevailing colors of the fresh rock are bluish gray or gray and are likely to weather dull gray or black. Some layers are mottled gray, blue, or white, and in many places are seamed with calcite. Southeast of Meadow Creek Mountain, the easternmost area in Tennessee, contains at its base, a considerable thickness of white magnesian (dolomitic) limestone or marble beds, but these are less prominent around Hot Springs. On these layers the black surfaces of weathered outcrops are most noticeable. Thin seams of blue and gray shale are present in a few parts of the formation, and a few beds of red shale in its upper layers make a transition into the overlying Watauga shale. Siliceous impurities in the form of sand grains are found in a few beds of the limestone, and chert is somewhat more common. This mineral usually forms small round nodules with gray surfaces and concentric gray and black bands inside. Another variety has the structure of chalcedony and occurs in lumps a foot or more in diameter. Over most of these areas the superficial part of the rock has been dissolved

[34] Op. cit. p. 5.
(The limestone varies considerably within short distances. That most commonly found is a blue or dove-colored limestone containing many rounded grains of quartz sand. Beds of this kind are very prominent immediately east of Allen Stand. Associated with these, * * * are considerable thicknesses of blue or gray oolitic limestone. The greatest thickness of the calcareous beds in this vicinity is about 300 feet. In places the siliceous material is so prominent that the rock becomes a calcareous conglomerate containing pebbles of quartz and feldspar. This phase is seen around Allen Stand, but is very local and passes within short distances into the more usual kind. The same variety appears 3 miles west of Deep Gap and again on Paint Creek about 3 miles above its mouth. Occasionally beds of limestone conglomerate are found especially north of Round Mountain (west of the Tennessee boundary). The pebbles in the conglomerate comprise the varieties of limestone which are seen in solid layers, and appear to have been derived from the breaking up of the layers nearly in position. This indicates that the deposit was formed in shallow water, where erosion could affect the newly formed beds.)

[35] Op. cit. p. 10.

[36] Op. cit. pp. 6 and 7.

by weathering processes, leaving a dark red clay which contains many lumps of chert. An exception to this rule is the high bluff of vertically dipping beds exposed along the French Broad River and close to the Southern Railway, a mile northwest of Hot Springs. The only other considerable exposure is to the west at Shut-in Creek, 2 miles from the railroad.

Structure.—The two areas of the Shady limestone near Hot Springs, as shown in Pl. V, sec. A-B, form the nearly vertical limbs of an inverted arch or syncline, the north side of the northern limb as well as both ends of both limbs being cut off by a curving fault of unusual character. (Pl. V, Madison Co. map), which is described as follows by Keith:

The great fault which passes just north of Hot Springs is one of the most unusual in the Appalachians. Its outcrop forms a nearly complete oval and its planes, if extended upward, would almost unite in a dome. Starting in an overturned fold southeast of Stackhouse, its plane dips successively toward all points of the compass and dies away in another fold parallel to and 2 miles northwest of its starting place. In its production are exhibited compression and shortening, not only in the usual northwest-southeast direction but in all others. The area inclosed by the fault plane thus represents a downthrown mass upon which the adjoining rocks were piled high from all sides. The plane cuts abruptly across the edges of the strata at many points, particularly where the mass of Max Patch granite is thrust forward upon them, and the usual connection of anticlinical fold and fault is not obvious here. * * * The dip of the plane varies from nearly flat at the foot of Bluff Mountain up to 50° or 60° east of Hot Springs. The evidence needed for measuring its maximum throw is not sufficient. It has, however, a displacement of at least three miles.

The north-south fault which passes 2 miles east of Stackhouse is similar to the foregoing fault in all its features except that its plane is not so curved This, too, gives evidence of a considerable shortening of the earth's crust in an east-west direction. To account for the features which faults of this kind exhibit, they must be considered as planes of shearing that pass through the granites and sedimentary rocks and are little influenced by the attitudes of the stratification planes. In this respect they differ widely from the prevailing Appalachian faults, which lie for the most part parallel to the stratification.

The Shady limestone in the vicinity of Hot Springs occupies two elongate areas of east-west trend. The southern, and by far the more important, extends from a little east of French Broad River westward beneath the town of Hot Springs, and along the mountain slope for 5 miles. Its width is about one mile. About a mile northwest of Hot Springs station it forms two prominent bluffs along the railroad which offer by far the best site for limestone quarrying in the district if not in the whole state. Both bluffs are on the property of the G. C. Buquo

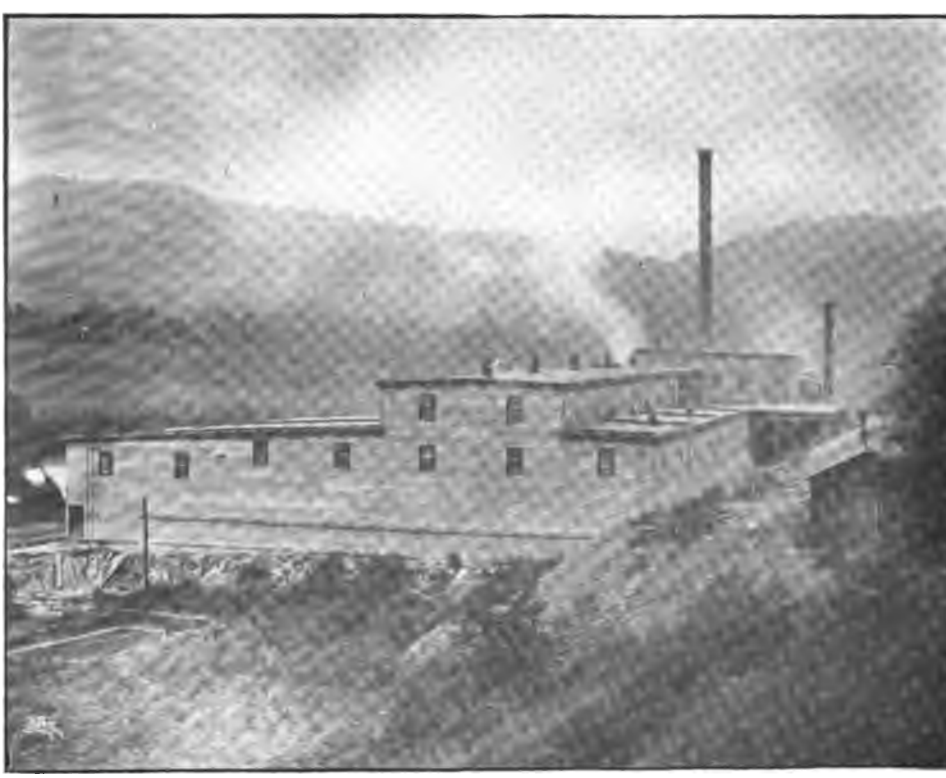
Lime Company, whose quarry is in the northern bluff. Westward from these bluffs the rock is almost entirely concealed beneath the brush and timber covered slopes. Only cobbles and small boulders of quartzite and schist, evidently derived from the Hesse and Nebo quartzites which form the higher slopes and summits just south of the limestone, appear on the surface and no adequate idea of the character of the limestone can be determined over most of its area. Cuts along the road just west of and above the bluffs show an overburden of 5 to 10 or more feet of red clayey soil. The only considerable exposure besides the two bluffs mentioned above is along Shut-in Creek, 2 miles west of Hot Springs. Other quarry sites favorable so far as drainage is concerned may be found where creeks cross the area in its western half, but the amount of stripping necessary is considerable, and distance from a railroad of 2 miles or more is unfavorable.

The northern area is about 2 miles farther north, and mostly underlies low ground in which the opening of quarries would involve considerable stripping and pumping, especially in parts of the area nearest the railroad. The parts underlying higher ground are not favorably enough situated to offer much inducement for development.

G. C. Buquo Lime Company.—The quarry of the G. C. Buquo Lime Company is in the northern of the two bluffs, about a mile northwest of Hot Springs station, and is connected with the railroad by a siding. The company's property covers 160 acres, including both bluffs, or all the most favorably situated quarry sites. The quantity of stone readily available is several million tons and at the present capacity of the grinding plant (20 tons an hour) is sufficient to last for about 200 years or more. The grinding plant is situated just north of the quarry with which it is connected by a short inclined track on which cars are operated by cable. The output is entirely pulverized limestone, 100 per cent of which passes through a 10-mesh, 85 per cent through a 50-mesh, and 50 per cent through a 100-mesh screen. See Plates IV and VI.

The quarry face when seen (August 1918) was about 100 feet long, and 50 fet high, and was worked on two benches. The stone blasted from the face was broken by sledges to proper size for the crusher. The beds strike westward at about right angles to the quarry face and dip about 75° northward. Individual beds vary from less than one foot to three feet in thickness and some are separated by films of reddish shale. Fractures are rather few and the prevailing absence of persistent horizontal fractures or joints detracts from the ease of quarrying, as it is difficult to maintain quarry benches in vertical beds without them.

A. First quarry opened of Blue limestone at level of Southern Railway Tracks.—G. C. Buquo Lime Co., Hot Springs, N. C.



B. View of rear of plant of G. C. Buquo Lime Co., Hot Springs, N. C.

The stone exposed in the quarry face is mostly dark blue fine grained dolomite, some beds of which are crisscrossed with short veinlets of white dolomite coarser grained than the main rock, and several of which contain scattered spots of similar white dolomite. The middle part of the quarry face are a few dolomite beds of light gray or bluish gray color, some with inconspicuous white veinlets. The white dolomite is somewhat rusted where weathered, indicating the presence in it of a certain amount of iron carbonate. This feature is confirmed by a qualitative test of some white dolomite from a veinlet in the dark blue rock. Application of dilute hydrochloric (muriatic) acid on five representative specimens, three of dark and two of light colored stone, produces no effervescence except along somewhat rusted veinlets and fractures. This result accords with a chemical analysis of the rock in column 18, page 150, furnished by the G. C. Buquo Lime Co., and said to represent the average output of the quarry. Recalculation of this analysis shows 59.50 per cent calcium carbonate and 39.65 per cent magnesium carbonate, or 86.85 per cent dolomite and 12.30 per cent calcite. Different analyses are said to show from 93 to 98 per cent total carbonates. Qualitative tests on the five specimens collected show a uniformly very low content of iron, most of which is present as iron carbonate in the dolomite grains, and the remainder in minute grains of fresh to oxidized pyrite.

Microscopic examination of the insoluble residues from these specimens represented by the 0.75 of sand in the analysis proves it to consist mainly of feldspar and quartz, with minute flakes or fibers of sericite (white mica) and tremolite, pyrite, and an occasional grain of apatite (a calcium phosphate). The feldspar and quartz have rather well-developed crystal outlines. In one residue feldspar was absent; in another it was the most prominent constituent. In one the leading variety of feldspar was soda orthoclase; in another it was ordinary ortholocase; and in a third it was soda lime feldspar (andesine) in detrital grains with secondary enlargements or rims of soda orthoclase.

Although this stone is quarried at present only for pulverizing, it is also well suited for road material, as shown by the physical tests on page 145, which compare favorably with other limestones and dolomites in the state as well as in the country. It is also apparently well suited for burning into high magnesium lime, and for chemical uses which call for high magnesium stone freer than the average in insoluble materials, and low, but not extremely low, in iron.

Other Properties.—The only available record of other attempts to quarry this rock has been furnished the writer by W. E. Carson,[37]

[37] Written communication.

who burned stone quarried on the opposite side of the river from the Buquo quarry. He states that it was a high calcium rock which burst in the kiln and choked the draft. High calcium rock is the exception in this vicinity. If, however, a sufficient quantity free from dolomitic beds can be found to encourage erection of a Portland cement plant, there are several shale or slate formations within reasonable distances, as shown on page 155, and railroad and water power facilities, as well as relations to markets, are also very favorable.

Mitchell County

INTERMONT (TOECANE)

The only deposit of marble or crystalline dolomite in Mitchell County is a lens in the Carolina gneiss which is exposed in a railroad

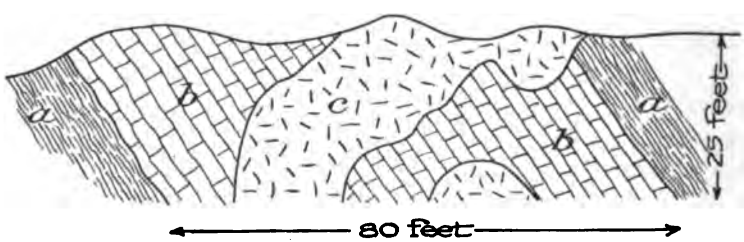


FIGURE 3.—Pegmatitic dike (c) cutting marble (b), which is overlain and underlain by mica schist (a). The schist at the contact with the marble is calcareous. (After Laney.)

cut on the north bank of North Toe River near the mouth of Sinkhole Creek, about three and one-half miles above Intermont (Toecane) Station, on the Carolina, Clinchfield & Ohio Railroad. This deposit was not visited by the writer, and the following description is substantially quoted from published reports by Keith[38] and Laney.[39]

According to Keith the marble crops out only near the streams and may extend considerably farther than its exposures indicate. It has been traced by Laney in a N. 20°-30° E. direction for about a mile from the railroad, its position being indicated by residual boulders here and there.

Keith states that along the river there are two bands of marble, alternating with mica gneiss, dipping about 50° SE. The entire series is cut through by an irregular pegmatite vein, which passes in places across the beds and in others along them. The upper layer of the marble is about 70 feet thick and the lower about 8 feet; the intervening mica gneiss is about 10 feet thick. (See fig. 3).

[38]Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Mount Mitchell Folio (No. 124), pp. 2-3, 1905.
[39]Watson, T. L., and Laney, F. B., op. cit., p. 204.

The following are records of 6 diamond drill holes, distribtuted through a distance of more than 300 feet, put down by the Sullivan Machinery Company for the Carolina, Clinchfield and Ohio Railroad Company, and kindly furnished by the railroad company:

Only schist and quartz reported to a depth of 543 feet	Clay and sand........ 6 Spar........... 3 Spar and quartz....... 3 Broken spar. 11 Broken schist 24 Decomposed schist....... 5 Broken schist 4 *Marble*......... 53 .... Schist......... 21 *Marble*......... 12 Schist quartz and spar...114	*Marble* with seams of sand. 19-3 Cavity. 2 *Marble*. 3-9 Broken schist 20 Schist..13 Quartz. 8 Schist..37 *Marble*.75 Schist..47	Gravel and rotten *marble* 5 *Marble*. 5 *Marble* with seams of sand.32 *Marble*. 3 Schist.. 1-9 *Marble*.39-3 Schist..80	Gravel......... 3 Broken schist 7 Decomposed schist....... 5 Schist.........41 Quartz....... 5 Schist.........10-6 .... *Marble*.........31 .... Schist......... 8-6 *Marble*.........39-6 Schist.........81-6 Quartz....... 3 Schist.........18	Clay and gravel...... 8 Sxhist.........10 Decomposed schist.......19 Decomposed spar.........12 Decomposed schist.......12 Schist.........10 Broken spar.13-1 *Marble*.........14-7 .... Schist.........10-4 Quartz....... 1 Schist.........20 *Marble*......... 3 Schist......... 7
Totals....	256	225	166	253	140

Material designated as schist and quartz between the two marble beds evidently represents the pegmatite mentioned by Keith and Laney, as well as any interbedded schist. These records show the varying thickness of the marble.

The marble is rather coarsely crystalline and has a white color wherever observed. The chemical analyses in columns 19 and 20 on page 150, show it to be a nearly pure dolomite. According to recalculation of analyses No. 19 the rock contains 54.8 per cent calcium carbonate and 45.02 per cent magnesium carbonate, or 99.82 per cent dolomite and 1.20 per cent calcite; according to analysis No. 20 it contains 55.9 per cent calcium carbonate and 44.27 per cent magnesium carbonate, or 96.97 per cent dolomite and 3.2 per cent calcite. A small part of the magnesium carbonate as calculated is probably replaced by iron carbonate.

The outcrops have a dark gray to black exterior. Near their surfaces there is some disintegration and the carbonate crystals weather into coarse crumbling grains. There are a few impurities in the shape of thin sheets and lenses of fine silica. These are folded and appear to represent originally different layers in the rock, although the silica is secondary. The contacts of the marble and mica gneiss are sharp and there is no transition to be seen. Along one of them slickensides show that there has been recent motion. The contacts with the pegmatite are equally sharp. For several feet at the bottom of the pegmatite there is a thin contact vein of actinolite which grades into the marble. Inclosed in the lower body of the marble there is also a small mass of serpentine and actinolite.

As a marble prospect, the favorable features of this deposit are proximity to the railroad, freedom from joints and minor fractures and impurities, and uniform white color. The principal disadvantage is the presence of the pegmatite vein or dike. The thickness of the main marble bed at the surface, 70 feet, is encouraging, but the accompanying illustration, after Laney, shows the necessity of thorough prospecting with the diamond drill to ascertain the workable volume of marble. Laney states that the pegmatite apparently extends the whole length of the marble deposit and even farther.

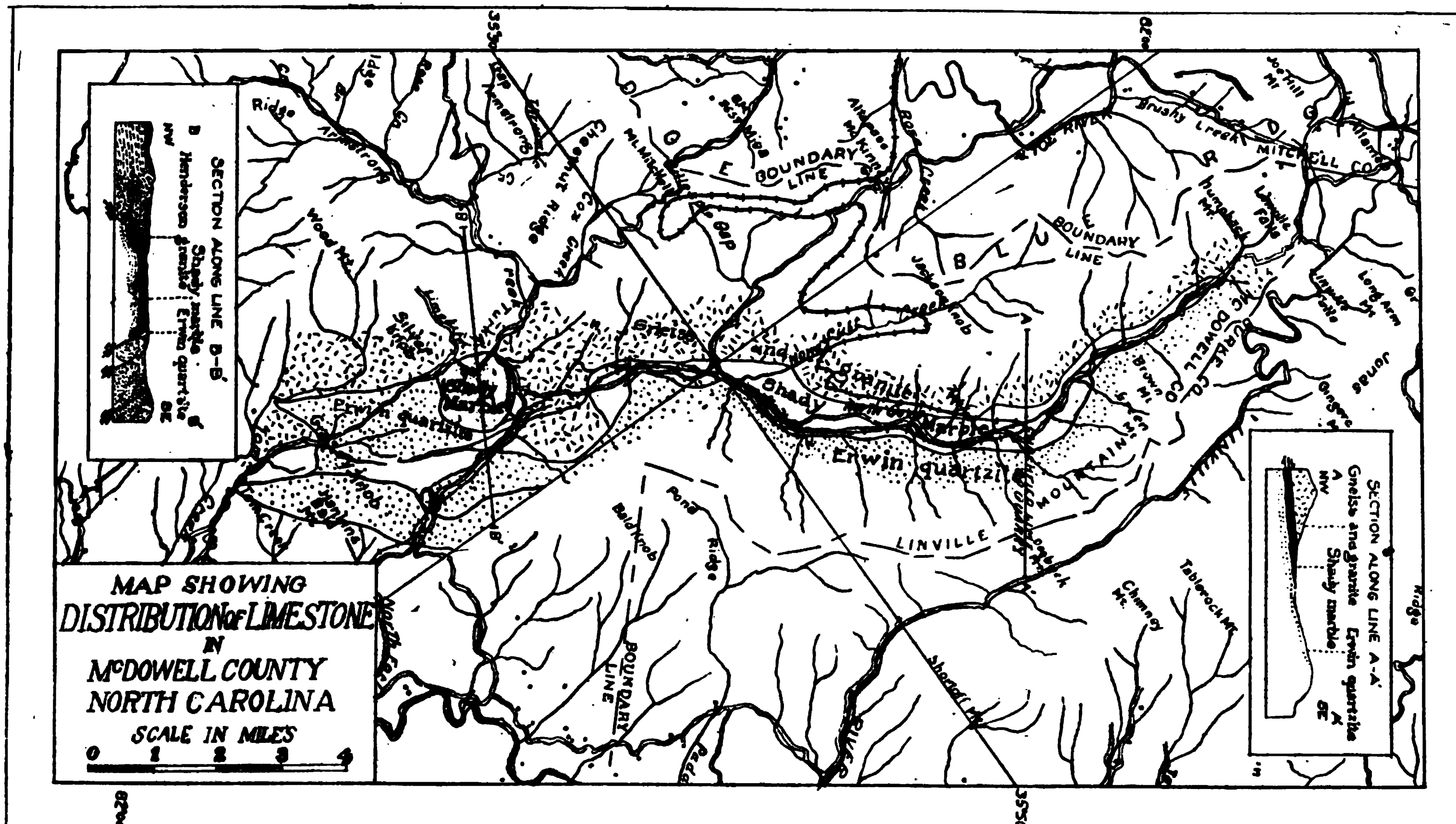
As a source of magnesium limestone for agricultural and different manufacturing purposes the deposit is very promising, although it may be a little high in iron oxides to meet a few very exacting requirements. A chemical analysis of an average sample showing iron oxides separate from alumina is necessary to determine this question. The coarse grain of the stone renders its wearing qualities inferior as ordinary crushed stone, but it should furnish satisfactory stone for terrazzo chips and finer ground material for such uses as chicken grit and coating of artificial stone.

McDowell County

The Shady limestone occupies three areas in the northern part of McDowell County, along or near the North Fork of the Catawba River. (See Pl. VII.) The northernmost and longest area extends along the North Fork from a few miles south of Linville Falls village to the vicinity of Sevier Station on the Carolina, Clinchfield & Ohio Railway, a distance of about 11 miles; the second, at Woodlawn, is of roughly circular outline, underlying the flat area of Turkey Cove and the lower part of the slope to the south; the third is at the bend in the river two miles southeast of Woodlawn.

The stone as a whole, described by Keith,[40] is prevailingly of white to gray color, with many beds of dark blue, fine grained, and of dolomitic character, its content of calcium carbonate ranging from 52 to 62 per cent, and its content of magnesium carbonate from 33 to 41 per

[40] Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Mt. Mitchell Folio (No. 124), p. 5, 1905.


MAP SHOWING
DISTRIBUTION OF LIMESTONE
IN
McDOWELL COUNTY
NORTH CAROLINA
SCALE IN MILES
0 1 2 3 4
SECTION ALONG LINE B-B'
Shady marble
Henderson granite
Erwin quartzite
SECTION ALONG LINE A-A'
Gneiss and granite
Shady marble
Erwin quartzite
Erwin quartzite
Shady
Gneiss
BOUNDARY LINE
LINVILLE
MOUNTAINS
Cox Creek
Chestnut Ridge
Wood Mt.
Jackson Knob
Brown Mt.
McDOWELL CO.
BURKE CO.
MITCHELL CO.
Brushy Creek
Humpback Mt.
Linville Falls
Long Arm Mt.
Joe Hill Mt.
Bald Knob
Pond Ridge
Chimney Mt.
Tablerock Mt.
Shortoff Mt.
Jonas
Ridge
Armstrong
Mt. Mitchell

cent. (See analyses on page 150.) The layers are thick and massive and the stratification is hard to determine unless large ledges are seen. Outcrops are very scarce, except of the beds near the base of the formation, which contain considerable silica in the form of sand grains and chert, and some of which have a high content or iron. The southern exposures, particularly, are considerably metamorphosed, or recrystallized, and the original colors have been largely destroyed, but in parts of the northern area metamorphism is less pronounced and the original dark blue and gray colors prevail. Many ledges of this kind have the black weathered surface which is characteristic of the formation. Owing to the scarcity of exposures its thickness is hard to determine, but it probably exceeds 500 feet in the Turkey Cove area. The top of the formation is not present in any of the three areas, unless in the southwestern part of the northern area.

The weathered rock is covered by a varying, but in most places rather thick mantle of dark red residual clay, which in turn is commonly covered by quartzite fragments washed down the slopes from the adjoining formation.

NORTHERN AREA

Northern Undeveloped Part.—The structural relations of the northern area are shown in (Pl. VII, Sec.AA′.) It is bounded on the west by an overthrust fault which has brought up Archaen gneisses and granites that form the steep mountain slopes adjoining the limestone valley. It is bounded on the east by the Erwin quartzite which forms the ridge separating Burke and McDowell counties and dips westward beneath the limestone at prevailingly low angles.

At the north end of the area, white crystalline magnesium limestone, representing the basal beds, crops out on the east side of the road to Linville Falls at the base of a steep slope. The formation here, as elsewhere in the area, is mostly covered by a considerable thickness of red clay which supports a thick growth of small timber. The limestone does not extend any considerable distance up the east slope, and, therefore, forms only a small mass available for local road building and agricultural use.

The rock is uneven grained, composed of thinly scattered groups of coarse grains (1 millimeter in diameter) in very fine grained matrix. It is only slightly stained by iron oxide, but a qualitative test shows it to contain a relatively large precentage of iron carbonate. It also contains more than the usual quantity of pyrite crystals, most of which are oxidized to dark brown or black pseudomorphs of brown iron oxide. Its high content of iron is characteristic of the basal beds of the Shady limestone. Its content of insoluble matter is also relatively high.

Microscopic examination shows this residue to consist mainly of feldspar and quartz, with oxidized pyrite and perhaps a little magnetite. The feldspar includes nearly perfect Carlsbad and Baveno twins of orthoclase, and considerable oligoclase. The nearly perfect crystal forms of these feldspars indicates growth within the limestone, either as new (secondary) crystals or as enlargements or recrystallizations of detrital grains that were deposited at the same time as the limestone.

A little to the south and along the west edge of the stream a ledge of similar stone extends for 1,000 feet or more, its surface sloping from about 45° towards the creek to vertical. The maximum height of the limestone above the creek is about 200 feet, and above it is a steep rocky, timbered slope rising 700 feet higher. The dip of the fault which separates the limestone from the overlying rock is at a low angle to the west. Extensive quarry operations, therefore, would soon involve underground work, in order to avoid the danger and expense of moving the great amount of overburden. Water power can doubtless be obtained from the creek. Transportation at present involves a three-mile haul over a rough down-grade road to the spur track of the Clinchfield Lime Company north of Linville Falls station. Plans for improving this road were under consideration in 1918. The rise from Linville Falls station to the down-stream end of this exposure is about 500 feet and is much steeper than the average during the last mile. The cost of hauling to the railroad is likely to be increased occasionally by the damage done by floods, and the total cost of operating a quarry is not encouraging in view of the fact that stone of similar or superior composition is being quarried at more favorably situated places in the state. The base of the limestone at this place is in or just below the creek bed, and the available stone therefore includes the impure basal beds described in the preceding paragraph, as well as the more pure beds in the formation.

The gently sloping ground on both sides of the branch creek at the northwest base of Brown Mountain is underlain by the limestone, but the surface is so thoroughly covered with timber and brush that the value of this tract as a quarry site can be determined only by the sinking of test pits or by drilling. The general conditions here suggest that a considerable overburden of soil and quartzite bowlders covers the limestone, and that only the lower 200 feet, or the less pure part of the formation is present. These remarks apply also to the wooded slope east of the road along the southwest base of Green Mountain, though purer rock may be found beneath the land within 1,000 feet east of the road. Most of this land is under cultivation. The southern end of this tract, about a mile northeast of Ashford (Linville Falls Station) appears the more favorable for prospecting.

On the west side of the river and due west of Brown Mountain, on the Avery and McGee tracts, the topography is more favorable for the opening of a quarry than at any of the localities thus far mentioned. The ground slopes at a moderate angle, and the dolomite extends as much as 200 feet above the valley bottom.

Analyses of the stone on the Avery tract and other places in the northern part of the area are given in columns 21, 22, 23 and 24, on page 150. They are all of dolomites, calcium carbonate ranging from 52.01 to 55.23 per cent, and magnesium carbonate from 40.75 to 44.17 per cent. The mineral composition of the carbonates is as follows:

	No. 21	22	23	24
Dolomite.........	94.09	95.30	97.17	89.65
Calcite...........	4.03	1.04	.52	3.11
	98.12	96.34	97.69	92.76

In No. 23, the carbonate approaches nearer to pure dolomite than in any other analyzed rocks in the State. A small amount of iron carbonate replaces a part of the magnesium carbonate, in all specimens qualitatively tested.

All of the analyses, except perhaps 24, are sufficiently pure to meet the requirements of stone for burning into lime. In view of the foregoing statements that in most parts of the area represented the lower, less pure portion of the formation is present, thorough prospecting should be undertaken before opening a quarry to determine whether these analyses represent a workable thickness of rock.

An unpublished report by V. V. Kelsey for the Carolina, Clinchfield & Ohio Railway, dated May 26, 1916, calls attention to the possible utilization of stone in the northern part of the area for marble. He refers to light-colored, mottled marble on the Avery tract, and to similar blue and light cream-colored marbles on the Henofer property as worthy of prospecting. Foregoing statements regarding impure, siliceous beds and beds with high iron content render careful conservative prospecting essential to determine the thickness of workable beds, the persistence of color below the superficial weathered portion of the beds, and the attractiveness and probable demand for such stone as can be furnished compared with that for marbles of similar colors already on the market. The remarks on page 63 regarding the adaptability of the better exposed stone in the Woodlawn area for marble may apply with equal emphasis to this area.

Clinchfield Lime Company.—By far the most favorable quarry site in the whole area is that occupied by the Clinchfield Lime Company, in the two spurs along the west side of the valley three-fifths mile and more north of the Carolina, Clinchfield & Ohio Railway. The company owns 350 acres, including the two limestone spurs, a farm on the low slope east of the creek, and the intervening flood-plain area. The quarry was opened in 1916.

The quarry in 1918 was equipped only for production of broken, crushed, and pulverized stone. Plans, however, have been made to install kilns and a hydrating plant. Quarry operations are outlined as follows: The rock is blasted by a series of 18-foot holes. A thin bed of mica schist, mentioned in the next paragraph, will presumably be used as the floor of an upper bench as the quarrying advances into the hill. The blasted rock is broken by sledges, or if too large by the adobe method of blasting, to pieces suitable for feeding into an Austin No. 5 gyrating crusher. It is conveyed to the crusher in end-dump cars. The crushed stone is elevated to screens which sort it to different sizes and drop it into storage bins, the screenings passing to a Jeffries pulverizer. The crusher has a capacity of 300 tons a day; the pulverizer 150 tons a day. They are operated by steam power. Stone from the bins is loaded by gravity into broad-gauge cars. The plant is connected with the railroad by a spur track 3,000 feet long with grade just sufficient to allow the cars to reach the main line by gravity.

The limestone dips westward, or into the mountain, at a very low angle. (See Pl. VII, sec. BB′.) The stone shown in the quarry face, in the southern spur (August 3, 1918), is mostly fine grained, dark blue dolomitic limestone, locally oxidized to purple. This extends upward from the quarry floor for about 20 feet and is overlain by a thin bed of white dolomite. This in turn is covered by a bed of mica schist 2 to 4 feet thick, which is followed by much broken dark blue dolomite, only a few feet of which have been uncovered at the top of the quarry face. At the south end of the quarry face irregular, broken masses of creamy white fine grained dolomite containing short thin seams of white mica are exposed beneath a considerable thickness of red residual clay. The overburden is irregular but as a whole very thin, and the cost of its removal becomes comparatively less and less as the quarry face advances westward and becomes thicker. It supports a considerable growth of timber. The top of the limestone on the spur west of the quarry face is about 200 feet above the creek. It is overlain by mica schist, much decomposed, and the exact contact is concealed.

The rock in the quarry face is much fractured. The dark blue, fine grained rock on close inspection is cut by many small partly sealed cracks, whose surfaces are marked by films of yellow to brown-stained calcite. Some fractures are slickensided, and stained dark greenish by films of chlorite. The rock just beneath this dark green surface may be bleached to light gray. A few short white streaks or lenses up to 2 inches in length are present, and are more or less rusted where weathered. These streaks, on application of dilute hydrochloric acid, effervesce more readily than the normal blue rock. Under the microscope the rock is on the whole even grained, with few if any grains as much as 0.1 millimeter in diameter. With a high power objective two kinds of grains are found, relatively large and small, the small forming networks among the large. This relation, together with the crumbling of the rock when immersed in dilute hydrochloric acid, suggests that the larger grains are dolomite and the smaller calcite. The high power objective also discloses a very few minute grains of quartz. Minute dark specks of pyrite, largely oxidized to limonite are thinly but uniformly distributed. Carbonaceous matter is very scarce. Leaching of the rock in 50 per cent hydrochloric acid leaves, as would be suggested by the foregoing description, only a very small residue of quartz, pyrite and limonite, and minute scales of white mica whose presence is not readily detected in thin sections of such fine grained carbonate rocks. A qualitative test proves the dissolved portion to contain a small but conspicuous percentage of iron which was present in the dolomite grains as carbonate.

Column 25 on page 150 gives a rather complete chemical analyses of the average dark blue rock made by State Chemist of the North Carolina Department of Agriculture. A partial analysis of average rock furnished by Mr. J. W. Grimes, manager of the company, shows an equivalent of 56.34 per cent calcium carbonate and 38.13 per cent magnesium carbonate, or 94.47 per cent total carbonates. Mr. Grimes states[41] that some stone in the quarry contains as much as 65 per cent calcium carbonate and 31 per cent magnesium carbonate, or 96 per cent total carbonates.

The one sample of purple stone is even finer grained than the dark blue stone, and contains somewhat more conspicuous coarser grained streaks partly oxidized. Stained surfaces of cracks show a little black manganese oxide as well as yellow iron oxide. Under the microscope the normal fine grained part is interrupted by linear, lenticular, and nearly spherical aggregates of coarser grains, some of them with multiple twinning. These are partly stained by brown iron oxide which is mostly developed along certain intermediate zones of crystal growth. This relation and the fact that the coarse grained streaks, touched with dilute acid, effervesce more readily than the rest of the rock indicate

[41] Written communication.

that the single coarse grains are made up of alternating growths of dolomite, calcite, and ankerite (calcium-magnesium-iron carbonate), the ankerite on weathering leaving the stains of iron oxide.

A very small quantity of stone considered by the superintendent, Mr. Poteat, to be unfit for burning into lime was noted on both spurs. That on the quarry spur was found just below the bed of mica schist, but was in too small quantity to be a serious factor in quarrying. A typical specimen from this place is mottled yellowish, fine grained gray dolomite with short residual streaks of bluish gray. Fracture surfaces are coated by yellow films of iron oxide and small black fernlike markings of manganese oxide. The specimen contains a quartz veinlet, 1 millimeter thick, and a few short streaks or rods of relatively coarse grained carbonate. Under the microscope the bedding of the rock is shown by alternating thin layers of different degrees of fineness, conspicuous grains in the coarser layers averaging only 0.1 millimeter in diameter. Carbonate grains in the coarser streaks or lenses are as much as 0.5 millimeter in diameter. Feldspar and quartz grains up to 0.5 millimeter in diameter are very thinly and unevenly scattered. They inclose minute carbonate rhombs. Wavy streaks and networks of yellow iron oxide are irregularly distributed. Grains of pyrite, mostly oxidized, tend to cluster near the coarse grained streaks, and a few irregular grains lie among the well shaped carbonate grains in these streaks.

Leaching of the rock in dilute hydrochloric acid leaves a sandy residue of dolomite grains. The dissolved portion contains very little iron. The dolomite residue is found by qualitative test to contain a conspicuous amount of iron carbonate. The very small insoluble residue left by the dolomite consists of quartz, white mica, a very few grains of feldspar, and minute dark opaque grains of oxidized pyrite.

Another specimen of dolomite rock unsuitable for burning was taken from the spur north of the quarry. It is nearly white, rather translucent and very fine grained but contains spots and short parallel streaks of rusted coarse grained carbonate, which contains a few dark grains of oxidized pyrite. Under the microscope the more conspicuous grains of the fine grained rock averaged about 0.03 millimeter diameter. The coarse grains in the spots and streaks range up to 0.5 millimeter in diameter and shows zones of limonite, similar to those described on page 61. Chemical test shows a rather high content of iron carbonate. Minor constituents are white mica in tablets 0.1 millimeter in diameter, and feldspar and quartz in occasional grains up to 0.2 millimeter in diameter. These three minerals were noted mainly in the coarse grained streaks. Minute pyrite grains are thinly scattered throughout.

The principal reason for rejection of stone represented by these two specimens is the prominence and irregular distribution of the rusted, or iron-stained material which would be quite as conspicuous in the burned rock. It is doubtful if there is an appreciably greater quantity of iron in these specimens than in the prevailing dark blue rock but it is more in evidence. The percentage of quartz, feldspar and mica is probably below the limit allowed in first class stone for burning, but these minerals are coarser grained and more unevenly distributed. This discolored stone may be included with the general quarry run for crushing and pulverizing, and for several chemical and metallurgical uses.

Southern Undeveloped Part.—Southwestward from Ashford the limestone is almost entirely concealed beneath the valley bottom. Quarries could probably be opened in the valley bottom of this area far enough away from the river for pumping to form only a minor item in the cost of operation. The location of quarry sites is dependent on drilling to determine the thickness of overburden and the quality of the stone.

On the southeast slope of the valley, from North Cove southwestward to its end, east of Sevier station, the surface of the limestone area rises as much as 200 feet up above the valley bottom, but the stone is so concealed beneath timbered soil and quartzite debris that no adequate idea of its commercial value can be obtained without considerable prospecting. An analysis of a sample from the Pitts tract, about a mile southwest of North Cove and east of the road, is given in column 26 on page 150.

WOODLAWN AREA

The greater part of the Woodlawn area underlies flat cultivated land as shown in Pl. VII, and is of little value as a quarry site compared with the slope to the south, on which dolomitic limestone is exposed for more than 300 feet above the valley level. The complicated and exceptional structural relations of this limestone deposit as determined by Keith are shown in Pl. VII, sec. CC′. It is nearly surrounded by a thrust fault which overthrusts the older granite, gneiss, and quartzite upon it from all directions except the southwest, and is similar in many respects to the fault in the Hot Springs district (page 51). Since the principal overthrust took place, secondary folds and faults have been developed and have bent and broken the earlier fault plane and the inclosing rocks.[42] Owing to these disturbances the dip of the limestone beds varies greatly within short distances, and the rock in most places has become so shattered that it is unfit for building stone, other than rubble. The rock on the slope is exposed along low spurs in which self-draining

[42] Keith, Arthur, U. S. Gol. Survey Geol. Atlas, Mt. Mitchell Folio (No. 124), pp. 6-7, 1905.

quarries can be opened with only a small amount of stripping. Connection with the Carolina, Clinchfield & Ohio Railway will involve construction of a spur track about a mile long to Woodlawn station on the east side of North Fork.

The rock exposed on the slope consists of alternating dark blue and light gray or drab beds from 2 to 10 feet or more in thickness. The dark blue rock is fine, even grained, cut by many small sealed fractures whose surfaces are stained yellowish brown by iron oxide. Under the microscope the more conspicuous grains, some of which have multiple twinning, averaging about 0.1 millimeter in diameter, are separated by a network of minute granules. From the manner in which the stone disintegrates when immersed in dilute hydrochloric acid it is suggested that the larger grains are relatively insoluble dolomite and the minute granules readily soluble calcite. Qualitative chemical test shows a rather considerable content of iron carbonate. Minor constituents are quartz, principally confined to one microscopic lenticular aggregate in the specimen studied, pyrite, largely oxidized to limonite, in minute thinly scattered minute crystals, and carbon in irregular linear aggregates of black specks associated with the calcite granules. The light gray rock is also dolomitic with the usual content of iron carbonate, microscopic quartz, white mica, and pyrite. It differs from the dark blue rock only in its freedom from finely divided carbonaceous matter.

The average chemical composition of the quarriable rock is shown by analyses Nos. 27 to 30, inclusive, on page 151. No. 27 represents a rock containing 97.61 per cent of dolomite and only 1 per cent of calcite, the nearest approach to pure dolomite of any rock in the state, except that represented by analysis No. 19. No. 28, an incomplete analysis, an equivalent of 90.1 per cent dolomite, and 3.2 per cent calcite. No. 29 represents an average sample of a 20-foot thickness of alternating dark and light beds in nearly vertical position along a dry stream bed about one-quarter of a mile south of the valley area. No. 30 represents an average sample of a small quarry face about 20 feet high of light gray and dark blue stone at an old limekiln near the mouth of the same dry stream bed.

These analyses indicate that the stone is well suited for flux, burning to high magnesium lime, and for chemical uses which require or allow the presence of a high per cent of magnesium, and require low silica and ordinarily low iron.

The qualities of the stone for road building, as shown on page 145 by a test made at the office of Public Roads and Rural Engineering, U. S. Department of Agriculture, adapt it for waterbound macadam roads of moderate traffic and bituminous roads of moderate to heavy traffic. It is doubtless suitable for concrete roads also.

The adaptability of the stone for marble is discussed as follows by Keith.[43]

"The lower beds of marble near the Erwin quartzite contain many sand grains and are not suitable for marble. Similar impurities are found in layers lying still higher. Silica is also present in the marble in the form of small grains and nodules of chert, which impair the quality of the stone. Considerable thicknesses of marble remain, however, which are suitable for ornamental stone. The total thickness of the formation shown in this region is over 500 feet. Probably the lower half of this is of little value as marble. * * * The dip of the strata at this point (south of Turkey Cove) is southeastward at angles ranging from 30° to 50°. At this angle the quarrying of definite beds of marble would involve handling a great deal of rock. Farther north in the cove it is probable that the dips are considerably less, but the quality of the marble in the bottom lands is unknown. Such outcrops as are found indicate that the marble resists weathering well. Its beds are usually massive and free from joints so that large blocks could be quarried. Near the Erwin quartzite, where the marble is overturned, some layers have developed a small schistosity. Such beds, however, are comparatively scarce."

According to Laney.[44]

"By far the greater portion of the stone is only a dolomitic limestone of varying purity. * * *

"* * * The portion of the stone that has been termed marble is usually very fine grained. The color is white with a tendency toward a blue tinge * * *, and is quite uniform. The stone is hard and compact, and breaks to a sharp edge. It contains varying quantities of quartz. * * * Sometimes there is only a very small amount of quartz present, while again the rock may be so siliceous as to be called a calcareous sandstone. This last condition is seen only very close to the southeast contact with the country rock. * * *

"The marble, while it is seriously injured by joints, is in much better condition in this respect than that portion of the stone which has been called limestone. As a rule, there are only two sets of joints varying from less than a foot to perhaps 8 feet apart. Thus, in some places, blocks of stone of good size may be obtained. The joints trend N. 20°-30° E. and N. 50°-60° W. and the beds of stone dip 45°-50° S. 45° E.

"Some years ago the State Geological Survey did considerable exploratory work in the marble beds on Col. J. G. Yancey's plantation at Woodlawn with a core drill. Several holes were put down in such a manner as to include a thickness of nearly 1,000 feet of stone. Records made at the time this work was done say that while much of the stone is rendered worthless by the jointing, some portions of it are fairly free from joints and will thus furnish valuable stone.[45] The cores from this drilling are now in the

[43]Keith, Arthur, op. cit., p. 9.
[44]Watson, T. L., and Laney, F. B., op. cit., pp. 202-203.
[45]Lewis, J. V., First biennial report of the State Geologist, p. 97, 1891-1892.

State Museum at Raleigh and were examined during the preparation of this report, but they are badly broken and furnished little satisfactory information as to the condition of the beds from which they were taken."

Although the stone, according to these quoted reports, is capable in places of furnishing blocks of commercial size, there is under economic conditions of the past two decades little encouragement for developing a marble quarry in competition with present quarries in North Carolina and adjacent states, where larger blocks of equally and more attractive appearance are produced. These active quarries, furthermore, are in high calcium marble which has a somewhat lower weight per cubic foot and a lower degree of hardness.

AREA TWO MILES SOUTHEAST OF WOODLAWN

The small area at the bend in the river two miles southeast of Woodlawn has not been visited by the writer and has received no economic discussion by earlier writers. As it consists only of the basal beds, it is probably too impure to be of economic interest in comparison with available stone in the other two areas.

Henderson, Buncombe, and Transylvania Counties

The Brevard schist, which extends in a northeastward course from Georgia, across South Carolina, and through Brevard and Fletcher to Graphiteville, N. C., contains a series of lenticular deposits of crystalline limestone. The Brevard schist is very similar in general character, including the presence of limestone lenses, to the Hiwassee slate in the Hot Springs, N. C., district, and the two are believed by Keith[46] to be parts of the same formation of Cambrian age. In Henderson, Buncombe, and Transylvania counties the formation consists mainly of schist and slate. Most of it is schist of a dark bluish-black, black, or dark gray color.

The limestone lenses as shown in Plate VIII are most numerous and largest between Brevard and a point four miles northeast of Fletcher. According to Keith's description, which is here quoted in substance, they consist of fine to medium grained crystalline limestone of white or nearly white color, but contain beds of blue, buff, and banded blue and white colors. Southeast of Lake Toxaway the carbonate of lime is largely replaced by silica and the rock has a cherty aspect. In the quarries near Fletcher the total thickness of the limestone lentil is about 250 feet and its length more than a mile. The quarries at the head of Boylston Creek show about 50 feet of limestone with a probable

[46]Keith, Arthur, U. S. Geol. Survey Geol. Atlas, Pisgah Folio (No. 147), p. 4.

length of one and one-half miles. The other lentils are both thinner and shorter. Owing to the great scarcity of outcrops it is possible that some of the limestone lentils are longer than shown on the map, and that some are entirely concealed beneath soil-covered valleys. The contacts of the limestone and the adjoining black schist are sharp wherever they are visible and there is no interbedding. No limestone deposits have been found more than four miles northeast of Fletcher, but they are found southwestward at intervals through South Carolina and far into Georgia.

DEPOSITS NORTHEAST OF FLETCHER

The two deposits in Buncombe County, northeast of Fletcher, lie beneath shallow depressions and afford no opportunity to draw conclusions regarding quality of the stone. The thickness of soil overburden no doubt varies, but can be determined only by trenching or boring. The quarrying has been carried on for many years, and the only evidences of former operations are the remains of a few small intermittent, or field, kilns and small excavations in which the rock is covered by wash in soil. One kiln is beside the road that crosses the southwest end of the longer deposit, and another is on the northeast side of Limestone Creek; but little or no limestone remains exposed at either place. Still farther north some prospecting was done, but the soil overburden was too thick (15 to 30 feet) for profitable quarrying.[47]

Prospecting for a satisfactory quarry site at any place northeast of the railroad, shown on Plate VIII, will require a considerable outlay of capital for trenching and boring; subsequent establishment of a quarry will involve besides the usual equipment for excavating stone, installation of a pumping plant, and either the hauling of the product by wagon or truck to Fletcher or Arden, or the laying of a long spur track. So far as distance from the railroad is concerned these two deposits are more favorably situated than any other in the district except that just southwest of Fletcher; but the amount of quarrying or prospecting thus far done is not encouraging for further development under present conditions of the limestone and lime industries.

Blue Ridge Lime Co.—The limestone lentil which extends for more than a mile southwestward from Fletcher, Henderson County, is the only one steadily worked, and was the only one in operation during August, 1918. The Blue Ridge Lime Company's quarry and kilns are on this lentil about one mile southwest of Fletcher by wagon road, or two miles by spur track. The quarry is on the Westfeldt property and is ad-

[47]Oral information from Captain Poteat.

vancing northeastward into the Lance property, now under lease to the Blue Ridge Company, where limestone was quarried as early as 1835.

The quarry pit in 1918 had a maximum length of about 300 feet, a width of about 250 feet, and maximum depth of about 40 feet. It is worked on three levels or benches, which follow the strike of the rock, each bench representing a different grade of rock. The rock is hauled up an inclined tramway by cable to the kilns or crusher. There are four continuous upright or stack kilns which are fired by a combination of coal and wood; one crusher, one pulverizer, and storage bins for crushed and pulverized stone, and storage room for barrelled lime. Steam power is used.

The limestone beds in the quarry dip 60° to 75° southeastward, and are classified into three grades: No. 1 and No. 2 for burning or crushing, and No. 3 for crushing only. The screenings from the crusher are pulverized. The three grades of rock are covered by only 2 or 3 feet of soil overburden.

The No. 1 stone forms the eastern half of the quarry. It is bluish white with distinct but not prominent black streaks along the bedding. Single beds are from 1 to 2 feet thick. The bedding planes are slickensided, and most of the movement due to folding and shearing of the formation was evidently along them. One bed plane near the southeast wall of the quarry coincides with a prominent fissure, or perhaps a bed fault, along whose foot wall the rock is somewhat contorted. From this bed fissure a branch fissure, rather open and rust-stained, extends obliquely upward to the northwest, beginning at the quarry floor and reaching the surface at the contact between No. 1 and No. 2 stone. With this exception the No. 1 stone is free from discoloration and from short, irregular fractures.

Microscopic and chemical tests show the No. 1 rock, if freed from black streaks, to be practically pure calcium carbonate in the form of relatively coarse calcite grains (up to 1 mm. in diameter) in a network of fine grains (0.1 mm. and less in diameter). A few pyrite crystals up to 0.1 mm. in diameter form thinly scattered inclusions in the larger calcite grains. The dark bands owe their color to finely divided pyrite in fine-grained calcite. They also contain a little quartz and considerable feldspar (partly albite and partly labradorite) in rounded and irreguar grains, many with Carlsbad and a few with albite twinning. The black streaks cover less than 5 per cent of the stone surface, and the pyrite and feldspar and quartz together constitute considerably less than half of their volume. The stone, therefore, is a high-grade, high calcium limestone, and, owing to its dense texture and freedom from minor fractures forms good lump lime. Should special requirements justify the added expense, stone free from black streaks could be selected that would furnish practically pure calcium carbonate or high calcium lime.

The No. 2 stone in the middle of the quarry is a creamy white, fine-grained dolomite, full of short, partly sealed fractures which lie in all directions. It is also cut by several major and minor joints or fissures, all of which are rusted. The fracture surfaces are partly stained by pale yellow films of iron oxide, and the more open bed planes may contain a little soft clayey or talcy material. In places the stone itself is impregnated with enough iron oxide to give it a pale yellowish tinge, but chemical test proves only a very minute quantity of iron to be present, either as oxide or carbonate. Under the microscope the rock appears of generally uniform grain, the conspicuous grains ranging from 0.2 to 0.5 mm. in diameter. Most of them show multiple twinning. Feldspar (labradorite) and white mica or talc in minute scales is very thinly scattered, and pyrite is even more scarce.

The practical absence of iron, except along the fracture surfaces, and the scarcity of insoluble impurities render this stone preferable to most dolomites or magnesian limestone and to all in North Carolina that have been tested, for certain chemical uses. The rock is said to break into small pieces, however, and to choke the kiln when burned alone. This behavior is evidently due to the opening of the many small fractures present in every lump of the rock and perhaps to a too rapid heating for dolomite.

Stone forming the southeast wall of the quarry is also classed as No. 2 stone. It is said to burn well, but not to make as white a lime as the No. 1 stone.

The No. 3 rock occupies the western 50 to 60 feet of the quarry. It is bluish white rock of fine to coarse grain, crisscrossed by films or seams of talcy material and much broken by slickensided and rusted joints. In places the talcy seams are an inch or more thick and form networks enveloping rounded and lenticular fragments of limestone. Pyrite is present in varying quantity, but is most prominent in the more talcy places and the slickenside joints, where it forms short vein-like aggregates half an inch or more thick. The carbonate portion of the rock is mainly calcite.

Under the microscope quartz is the principal impurity and forms small spherulitic or agate-like and vein-like aggregates, as well as scattered grains. The talc appears as feather-like aggregates that penetrate the calcite portion. Other minor minerals are wollastonite (calcium silicate) and probably tremolite (calcium-magnesium silicate), which are inclosed in talc aggregates. The dark-green patches on some of the talcy surfaces of specimens suggests the presence of chlorite (magnesium-aluminum-iron silicate). The absence of any considerable quantity of magnesium in carbonate form suggests that although the rock originally was a siliceous magnesian limestone the magnesia and a little of the calcium oxide combined with the silica to form talc and the other silicates, leaving the calcium carbonate to recrystallize as calcite. Chemical tests on two specimens showed one to contain considerable soluble iron (evidently carbonate for the most part) and the other to contain only a negligible amount.

The rock is said to crumble and choke the kiln on burning, also to develop black slaggy spots where large pyrite grains or aggregates are present. It is therefore used only for crushing, and the more talcy, pyritic material is discarded. The crushed and pulverized stones are derived in part from this stone and in part from any No. 1 and No. 2 stone that has been broken to sizes too small for use as crushed stone.

An average analysis of all the grades, as represented by the pulverized product, shows 75.03 per cent calcium carbonate and 21.66 per cent magnesium carbonate, total 96.69 per cent. Mr. Grimes states that some stone from the quarry contains as much as 97 per cent calcium carbonate. This is evidently No. 1 stone comparatively free from black streaks. Were the demand for special high grades of lime sufficient to justify the extra cost of careful selection, analyses Nos. 34 and 35, page 151, indicate that No. 1 and No. 2 stone can be selected sufficiently free from impurities to satisfy the most exacting requirements. Were unusually pure high magnesium lime in sufficient demand, No. 2 stone could be satisfactorily burned in a rotary kiln, where the process of burning is not impeded by disintegration of the rock.

DEPOSITS SOUTHWEST OF FLETCHER

Limestone lenses southwest of Fletcher have been worked or prospected for local supplies of lime at and two miles northeast of Boylston in Henderson County, and two miles northeast of Ecusta in Transylvania County, but most of the few openings are too small and covered by fallen soil to give an adequate idea of the extent and quality of the limestone as a whole. The quality of the lime, burned mainly for local agricultural use, is said to have been excellent. No quarries or kilns were in operation during 1918. Outcrops also are very scarce. The quarries at Boylston have been briefly described as follows by Laney.[48]

"On the land of Mr. J. F. Woodpin, about three-fourths of a mile a little east of south of the Boylston gold mine, limestone has been worked for a little over 200 feet along the strike. The limestone apparently contains very little grit

[48]Watson, T. L., and Laney, F. B., op. cit., p. 208.

and is of a bluish tinge known locally as "blue limestone." Considerable of this limestone has been burned to lime, some of which has been used for fertilizing purposes. On the W. B. Allison farm, three-eighths of a mile due west of the Woodpin quarry, the limestone is whiter in color and is known locally as "white limestone" to distinguish it from the "blue limestone" of the Woodpin quarry. A similar quarry has been opened on Bryson Ezell's farm three miles northeast of Allison's. Considerable of the lime burned from this limestone has been used for building purposes."

The deposit northeast of Ecusta extends along the northwest slope of a broad ridge and parallels the road which crosses the divide between Silver Creek and Boylston Creek. It has been worked four places at least, but with one exception the quarry faces are almost completely hidden by soil washed down from the thick overburden. As the strata dip steeply southeastward, or into the ridge, development in that direction as well as downward will increase the quantity of overburden to be handled. The southernmost and largest quarry southeast of the point where Silver Creek crosses the road has a face about 30 feet high, but only in a quarter of it is rock well exposed. The rock is dark blue dolomitic limestone, much of it stained yellow and brown along mud seams, joints, and small tight fractures. To judge from the exposures available for study, only lime of inferior quality is to be expected on the whole—suitable only for local agricultural use as well as for mortar. The quarry is about three miles from the nearest railroad station.

This quarry in 1918 was equipped with narrow gauge tracks and a few cars for conveying the rock to an intermittent stone kiln. Its position on the slope afforded a fairly good opportunity for the disposal of waste.

For 12 miles from Ecusta southwestward no deposits of limestone have been found in the Brevard schist. Three comparatively small deposits are distributed through the next seven miles. One of these is a mile and a half northwest of Rosman, another about two miles southwest. The third extends for three-fifths of a mile along the lower part of Bear Wallow Creek from its junction with Toxaway River. According to Laney,[49] the limestone outcrops prominently in the stream and on both sides in ridges that rise about 150 feet above the creek. Although this limestone is somewhat siliceous, it was for a number of years quarried and burned for both building and agricultural purposes. No production has been reported in recent years.

Jackson County

Impure crystalline limestone or marble exists at Caney Fork, Jackson County, but is so remote from railroads and is of so little commercial

[49] Op. cit., p. 208.

importance that it has not been visited by the writer, and no descriptions of it have been published. A partial chemical analysis of it is given in column 36, page 151. The high percentages of silica and alumina imply the presence of considerable quartz and mica or feldspar, and that of iron oxide a smaller quantity of black mica, hornblende, magnetite or pyrite. The difference between the total and 100 per cent is probably accounted for by the alkalies, potash, and soda, in feldspar and mica. Were the stone less remote from transportation facilities it would be of interest to prospective producers of Portland cement, as its ratio of silica, alumina, and iron to calcium carbonate is only a little too high and could be corrected by addition of a small quantity of high-grade high calcium rock. It may be of some local interest as a material hydraulic cement. For agricultural use it has less than four-fifths the amount of active lime and magnesia that most of the other stones of the state represented by analyses have.

Cleveland and Gaston Counties

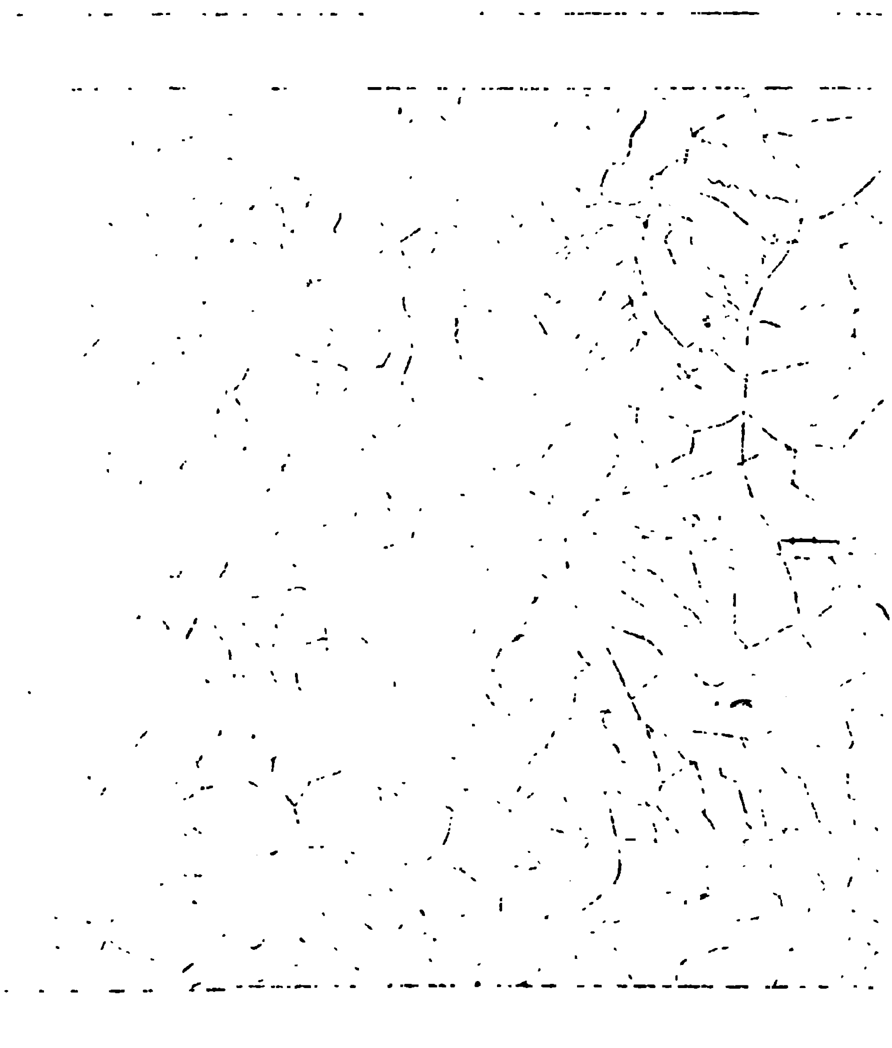
Gaffney Marble

Extent.—Crystalline limestone, or marble from a strictly petrographic standpoint, forms a linear group of narrow bands extending northeastward from Gaffney, past Blacksburg, S. C., across the southeastern part of Cleveland County, N. C., and into Gaston County. It lies one-half a mile east of the town of Kings Mountain and pinches out about a mile west of Bessemer City. It has been mapped in detail by Keith and Sterrett of the U. S. Geological Survey, and because of its greatest development, both geologically and commercially, at Gaffney, S. C., it has been named by them the Gaffney marble.[50] The following description is substantially quoted from these authors:

The outcrops are generally obscure, and the majority of them have been prospected by pits or worked by quarries. Most of them occur in low ground along the valleys of streams. To the south and east of Grover, at the south boundary of North Carolina, there are two limestone belts, in both of which quarries have been opened; but from a half-mile north of the boundary to Bessemer City only one belt has been located. This, as shown on the map (Pl. IX) is interrupted for one and one-fourth miles about halfway between the town of Kings Mountain and the state boundary.

The geologic structure in this district as elsewhere in the Piedmont and mountain areas of North Carolina is complicated. The rocks are

[50]Keith, A., and Sterrett, D. B., U. S. Geol. Survey Geol. Atlas, Gaffney-Kings Mountain Folio (No. ——) in manuscript.



upturned by folds and the folds are complicated by thrust faults which extend parallel to the marble belt. Detailed study, however, has shown that the marble is the youngest of the formations in the district and rests upon the Blacksburg schist, a formation 800 to 1,000 feet thick which varies from a fine-grained graywacke (an impure variety of sandstone) to sericite schist, named by Keith and Sterrett,[51] from the town of Blacksburg, S. C. Both formations are of probable Cambrian age. Near the marble this schist contains increasing quantities of calcite and grades into it. Both the schist and the marble are weathered to clayey soils and the gradation zone is characterized by a reddish-brown very fertile soil.

The beds as a whole dip steeply to the southeast, and the Blacksburg schist forms both boundaries of the marble throughout most of its extent. In a few places faults have removed the underlying formations and brought the Carolina gneiss up against the marble. This is notably the case where the marble belt is ended south of Gaffney by the overthrust Carolina gneiss.

The unusually great width of the deposit at Gaffney, S. C., is due to repetition of the beds by folding.

Character.—The Gaffney marble is a rather variable formation ranging from very fine to medium fine grain and from bluish-gray to white in color. Most of it has a schistose or banded structure made more evident by the presence of impurities such as mica and hornblende. Outcrops of the Gaffney marble observed in the different deposits range from 30 feet to about 300 feet across in the Whisnant quarry, two-thirds of a mile southeast of Grover, in South Carolina. There the beds are apparently duplicated by folding and have a dip of 35° NW., so that the thickness of the marble formation would be less than 120 feet. At least 50 feet of mixed pure and impure marble is exposed in the large pit of the Gaffney Lime Co., but this is not the full thickness of the formation at this place.

The purer grades of marble consist chiefly of granular calcite, with small quantities of quartz, biotite, or phlogopite, and tremolite or other light-colored hornblende. In some places epidote and pyrite are present. Earle Sloan has pointed out that the Gaffney marble is highly magnesian in some places, one of the upper beds in the Gaffney limestone quarry carrying 41.19 per cent carbonate of magnesium. The blue marbles have been found to be the purest in lime and the white beds carry more magnesia.

The less pure marbles contain quartz, muscovite (white mica), biotite (black mica) and dark amphibole, and epidote, in increasing quantities and accordingly grade into calcareous mica and hornblende gneisses and schists. Calcite adjusted itself during metamorphism by a recrystallization of its numerous grains which do not markedly display schistose structure when other minerals are absent. Other minerals of the impure marbles,

[51]Op. cit.

such as mica and hornblende, yielded to metamorphic forces and their broader and larger dimensions have been turned into approximately parallel positions producing schistosity and, in many cases, banding also.

A typical specimen of the limestone near Kings Mountain was taken about one-half a mile southeast of the town, where the zigzag road crosses the headwaters of Kings Creek. This rock is dark bluish-gray, and composed of thin bands up to one inch in thickness of finely crystallized limestone separated by films of dark gray finely micaceous material (phyllite). Parts of it are criscrossed by short white calcite veinlets. The thickest layers of limestone seen anywhere along Kings Creek did not exceed one foot in thickness. In places the limestone and phyllite form alternating layers from one-quarter inch down to mere films in thickness, and a few phyllite layers are as much as half an inch thick. In thin section a comparatively high-grade limestone band proved, under the microscope, to contain considerable quartz and white mica, the mica forming streaks and giving a pronounced schistose structure. Mica appeared to constitute as much as 30 per cent and quartz 10 per cent of the rock. Graphite in minute black specks irregularly distributed along the mica layers is responsible for the dark color. Pyrite forms a few irregularly scattered grains up to one-fifth millimeter in diameter and partly oxidized.

Weathering.—In most places the Gaffney marble has weathered away rapidly to the depth of ground water or deeper. Because of this easy weathering longitudinal valleys or lines of low gaps and topographic depressions have formed along the marble belts. Weathering has taken place in the manner usual with limestone or marble, that is, by solution at the surface and along joints and fissures. In this way irregular channels have been eaten through the marble and in places only nodular masses of the rock have been left scattered through residual clay. The soils resulting from the weathering of the marble generally consist of dark red or brown sticky clay representing the decomposition products of the original impurities of the rock.

Economic Value.—Although the rock is termed marble because of its crystalline texture, there is little to give it commercial recognition as a marble; as a limestone it is handicapped, at least in North Carolina by the prevalence of impurities, and the low position of its outcrops at stream level, which involves considerable expense in stripping and pumping for the opening even of a comparatively small quarry.

More than 15 quarries have been opened at different times in this limestone belt, particularly in the South Carolina portion of it, but only one, near Gaffney, has been worked at all extensively. Operations there ceased in 1913 because of the increasing quantity of overburden to be removed and the cost of pumping. The other quarries have been worked intermittently, and the stone burned for local use. These were commonly developed from outcrops found in stream beds. At only three quarries, all in South Carolina, have modern continuous kilns been installed, but no production has been reported from them during recent years.

The quarries contain bluish-gray and white beds. In some quarries two beds of the bluish rock, separated by a few feet of calcareous biotite or hornblende schist have been worked. Single beds of the bluish rock are not more than 10 to 15 feet thick. This rock is said to make good lime, but most of the white stone is discarded, presumably because it contains microscopic impurities or because it is dolomite and does not burn well under the conditions that yield good, high calcium lime. Some of the stone unfit for burning has been used for local construction purposes.

A few places may be mentioned as comparatively favorable quarry sites, so far as drainage is concerned, but in the general absence of outcrops nothing can be said regarding the quality of stone at them. It should be superior to that described on page 73 to be of economic importance. These sites are east and northeast of the town of Kings Mountain where the limestone belt crosses the slopes of creek valleys. The most favorable site is on the steep slopes of the short branch valley on the south side of Abernethy Creek, one and a half-miles northeast of the town of Kings Mountain. This place is only two-fifths of a mile from the railroad and can be connected with it by a spur track of easy grade. The other sites are now under cultivation and it is probably more economical under present conditions for the owners to buy what lime they need than to go to the expense of opening quarries for local trade or to compete with present producers for more extensive markets.

LIMESTONE AT KINGS MOUNTAIN GOLD MINE

Crystalline limestone, or marble, of variable character forms a bed of considerable size in the Carolina gneiss at the Kings Mountain gold mine. It is of medium to fine grain, of white to gray color, and of dolomitic composition. It has never been quarried, and, as shown by the map (Pl. IX), is too far from a railroad to be of more than local interest.

Lincoln and Catawba Counties

Deposits of dolomitic limestone in Lincoln and Catawba Counties, presumably northeastward continuations of the Gaffney marble belt, were worked intermittently in a small way several years ago, but as available information concerning them indicated that they were remote from transportation lines and of little importance, even for supplying local demands, they were not visited by the present writers. A manuscript report made on two of these quarries in 1917 by John E. Smith for the State Geologist is here quoted:

OLD LIMESTONE QUARRY OF CATAWBA COUNTY[52]

From the town of Maiden, south of Newton, extending in a northeasterly direction to the Catawba River or slightly beyond it, lies a narrow belt of crystalline rocks in which there is a series of outcrops of dolomite. One of these described in this report occurs five miles south of Catawba station, on the Trullinger estate and is known as the "Old Limestone Quarry of Catawba County," having been worked intermittently for more than half a century. This is in the Piedmont Belt and on the western margin of an elongated area of Triassic and crystalline rocks that extend southward through Lincoln and Gaston Counties into South Carolina.

The outcrop occurs in the bed of a small headwater branch of the North Fork of Mountain Creek and along the bottom of the narrow valley of this stream. It is in this position chiefly because the dolomite responds more readily to the agencies of weathering and erosion that have formed the valley than do the more resistant schists on either side of it. The direction of the stream here parallels the strike which is south 20° west by north 20° east. The dip is toward the northwest and varies from 15° to 60°, averaging between 30° and 40°.

GENERALIZED SECTION

9. Schist, in part talc and chlorite.	
8. Dolomite, impure, brown, streaked with iron, fine grained crystalline, irregular in extent, exposed	4 feet
7. Dolomite, blue with some white irregularly mixed	3 "
6. Dolomite, with thin streaks or dark blue and white, giving a gneissoid appearance	2 "
5. Dolomite, fine grained, crystalline, compact, white, with a mixture of dark blue, not fully exposed	6 "
4. Dolomite, white, much like 5 with less impurity	5 "
3. Dolomite, white with numerous quartz veins	4 "
2. Dolomite, a mixture of the dark and white	5 "
1. Dolomite, white in part, poorly exposed	2 "
0. Schist, quartzose in part.	

The variations in color indicate impurities, in part iron and organic matter, which occur as very thin streaks, small flat lenses and to some extent as granules promiscuously distributed. The dolomites are fine grained and crystalline throughout and are generally compact and solid.

[52]This may be the Powell quarry represented by analysis No. 37, page 151.

The specific gravity of the white is 2.795; of the mixed dark and white, 2.81; of the dark blue, 2.84. Numbers 2, 4 and 5 of the generalized section are of good quality and relatively free from impurities. The section given is composite. This with the limited number and extent of exposures, and the irregularity of the beds makes the estimates somewhat inaccurate.

The rock is exposed in the quarries and in the bed of the creek on the east. Its length is approximately 500 feet and its width varies from 30 to 60 feet. The available stone has been removed from approximately four-fifths of this area and much of that used has been taken from below the level of the ground water to a depth four to ten feet. The outcrops clearly exposed range from the water table to six feet above it with an average of possibly four feet.

Tests and analyses show that very nearly one-third of the dolomite consists of magnesium carbonate ($MgCO_3$). Of the dark blue dolomite 30 per cent is insoluble matter and 15 per cent to 20 per cent of insoluble matter was found in the white and mixed dolomite.[53] This leaves but little more than one-third of the blue rock for use as a soil amendment and only half of the white and mixed colored dolomite.

A careful estimate shows that approximately 300 tons of dolomite of good quality are available above the ground water level and it is probable that 1,000 tons more could be secured by lowering the water in the quarry with a siphon or pump.

The overburden is four to eight feet thick and consists of soil, silt, and fragmental rocks with numerous trees six inches to a foot in diameter, also thickets of vine and shrub. A large part of the stripping removed from the exploited portion of the area now lies over the remaining part of it.

There are three lime kilns in the side of an embankment near the quarry; one of these has been used within the past year and is in fairly good condition. The elevation of the top of the kiln is about 25 feet above the upper surface of the dolomite in the quarry.

THE SHUFORD LIME QUARRY.

This is located about eight miles south of Catawba station in Catawba County. It is about two miles south of Edith where the road crosses from North Fork of Mountain Creek. The part of the old Shuford tract on which it is located is now known as the Johnson place.

The old lime kiln, now in ruins, is on the bluff by the roadside about

[53]These percentages of "insoluble" are much higher than the total silica, alumina, and iron in the inferior analysis (No. 87, page 151) of stone from the Powell quarry, which is close by, if not the same as, the quarry here described.—*G. F. L.*

150 yards north of the bridge and the quarry site was evidently along the creek at the foot of the bluff where a small outcrop of dolomite bearing drill marks can now be seen. Most of the quarry has been filled by a number of alluvial fans partly overlapping and apparently 4 to 8 feet deep. These fans extend from the foot of the hill to the creek (8 to 12 yards) and are now covered with young trees that have grown up from stumps. The valley here is about sixty yards wide.

The rock seen is a white to dark dolomite, massive, thick bedded, and is best exposed in North Fork about 15 yards above the bridge, where it has a thickness of 10 feet more or less. The strike here is south 20° to 30° W., and is nearly normal to North Fork where it crosses it, and nearly parallel to the steep bank which was probably a part of the old quarry face. The dip is to the west 65° to 75°, and under the hill. Practically all of the dolomite has been removed to the level of the water table. This rock is cut by dikes of basalt and is in contact with amphibolite schist above it. The amphibolite occurs below it also but the contact is covered, the two being 50 or 60 feet apart where observed nearest together. The dolomite, therefore, may be much thicker than that seen in the outcrop.

The Shuford Quarry once was worked by Mr. McNinch of Charlotte, for tombstones, which were sawed from quarry blocks at a mill on the property.[54] A sufficient analysis of the stone was made to indicate its dolomitic character.

KEENER QUARRY

To the southwest of the Shuford quarry and about 8 miles southeast of Lincolnton is the old Keener quarry in Lincoln County. No stone has been quarried at this locality for a great many years. The limestone is dolomitic and is of blue and white varieties. This deposit was examined by Mr. John E. Smith, who reported that no dolomite is now exposed in the quarry except at the creek and its branches. There is an overburden of from 5 to 25 feet with no favorable place for its disposition. On account of its location, if quarrying is carried on here it would necessitate continual pumping during excavation of stone. The limestone contains from 50 to 75 per cent of calcium carbonate and as high as 12 per cent of insoluble residue. An analysis of this rock made in 1892 is given in column 36 of the analysis on page 151.

FINGER QUARRY

Four miles east of Lincolnton in the same belt of dolomitic limestone as the Keener quarry is the Finger quarry. Little is known regarding

[54] Letter from W. A. Graham to J. H. Pratt, State Geologist, December 27, 1916.

this quarry except that when iron ore was being mined in that section of the county this quarry produced a certain amount of limestone. Analysis of the ore showed that it contained 30.9 per cent of lime and 13.5 of magnesia. Analysis of this limestone is given in column 37 page 151.

Stokes and Yadkin Counties

There are several other small deposits whose location or quality renders them of very little commercial value, and which it did not seem worth while to visit. One of these near Germanton, Stokes County is a bed 40 to 50 feet thick, and was worked at the Bolejack quarry to supply lime for local use and for burning into lime prior to the Civil War. It is said to underlie a flat area beneath considerable overburden. Pumping will therefore be necessary, as will the improvement of three miles of rough road which separates the quarry from the railroad.

A deposit on the south (Yadkin County) side of Yadkin River near Siloam (Surry County) was worked a few years ago by the Lime Rock Lime Company. The rock was conveyed by cable to a pulverizing plant on the north bank of the river. The plant was destroyed by a flood in 1916.

Orange, Durham, and Wake Counties

As reported by W. C. Kerr,[55] former State Geologist of North Carolina, "there are frequent outcrops of a bed of marl and impure limestone two to four feet thick over a territory of 15 or 20 square miles, the nearly horizontal strata coming to the surface in ravines and gullies and exposed in ditches, wells, etc. Near Brassfield turnout, on Mr. W. Rochell's place, is an exposure of nearly 4 feet of alternate thin beds of a compact light gray and red arenaceous limestone, with strata of uncompacted brick red, marly clay between. This middle portion contained 24.07 per cent of carbonate of lime and 7.52 carbonate of magnesia. . . . The upper indurated strata contained more than 90 per cent of carbonate of lime and the lower about 60. . . . Lime was made at this point during the war (Civil War) and used for building purposes in Raleigh. And some 40 years ago (about 1835) a few kilns were burned for the same purpose at a point a few miles southeastward. There is an outcrop of a very similar character at Mr. H. Witherspoon's, 2 miles east of B."

[55] Geology of North Carolina, Vol. I, 1875, p. 187.

PART III

LIMESTONE AND MARL OF EASTERN NORTH CAROLINA

By E. W. Berry and J. A. Cushman

INTRODUCTION

In the early history of North Carolina before the development of adequate transportation facilities, each locality was essentially self-supporting and as for over one hundred years after its foundation the state contained no towns over one thousand inhabitants, it is obvious that the considerable population was rural and devoted to agricultural pursuits. After the land was cleared and tilled, the only sources available to prevent its deterioration were local supplies of fertilizers, namely: stable manures, marl beds, and muck or peat deposits. Consequently all the better farmers in areas where marl was present opened pits and used the marl for top dressing.

The extent of the interest in natural fertilizers may be gathered from the space devoted to this subject in Kerr's Geology of North Carolina, published in 1873. Kerr's report or the earlier reports of Emmons give an admirable portrayal of the extent to which marls were utilized in the early days. During the last two decades of the last century the development and diversification of commercial fertilizers proceeded simultaneously with improved means of communication. The ease with which such fertilizers or burnt lime could be secured and their more satisfactory results for special crops, or as compared with some of the lower grade native marls, led to the gradual disuse of the marls by the farmers of the state except in a most desultory way.

The present demand for farm products, combined with the shortage and consequent high prices of lime and commercial fertilizers and the unparalleled pressure upon transportation facilities, has led to a reawakening of interest in the native marls, information regarding which is set forth in the following pages. It should be clearly understood that none of the marls of the state are true fertilizers except to a very slight degree, and they contain none of the more important plant foods, such as nitrates. They are to be looked upon as soil correctives both as regards its chemical composition or sourness and its physical composition or texture. When used in conjunction with green manures or swamp muck marl not only eliminates acidity and non-workability but facilitates the composting and the chemical activity of the organic manure and in this sense it may be regarded as a fertilizer.

AREA COVERED BY THE REPORT

Eastern North Carolina, as limited in the present report, comprises that part of the state known as the Coastal Plain. This physiographic division is a segment of the broader province of the same name which borders the Atlantic from New England to Mexico. In North Carolina that part of the Coastal Plain above tide ranges in width from 100 to 125 miles, extending westward from the present coast to the Fall line which forms its western boundary, dividing the unconsolidated rocks of the Coastal Plain from the hard crystalline rocks of the Piedmont Plateau which borders it on the west. The Fall line is a sinuous boundary extending from the falls of the Roanoke at Weldon southwesterly to Anson County, marking the head of navigation of the principal streams and a rather sharp change in altitude, soils and geological structure. The Coastal Plain embraces about two-fifths of the total area of the state, being over 20,000 square miles in extent, and including all or parts of forty-two counties. The country is prevailingly low and flat, particularly the eastern counties, rising gradually westward as a series of more or less dissected terraces to a few hundred feet above tide in the "sandhill' country along the Fall line.

Geologically the Coastal Plain is the youngest portion of the state and its rocks and soils are, for the most part, unconsolidated clays, sands and marls, deposited as sediments in the marginal waters of the seas which at various times in its history covered more or less of this region. These sediments range in age from Cretaceous to Recent and such parts of them as have escaped erosion form the surface of the country in the areas shown on the accompanying map, Pl. X.

GEOLOGICAL FORMATIONS OF EASTERN NORTH CAROLINA

The following table gives the sequence of Coastal Plain formations in North Carolina that are recognized at the present time by geologists, arranged in order from youngest to oldest:

Cenozoic.			
Quaternary:			
Recent Pleistocene	Pamlico formation....	Columbia group.	
	Chowan formation....		
	Wicomico formation...		
	Sunderland formation.		
	Coharie formation.....		
Tertiary:			
Pliocene	"Lafayette" formation.		
	Waccamaw formation.		
Miocene	Yorktown formation..	North of Neuse River	Duplin Marl South of Neuse River
	St. Mary's formation..		
Eocene	Castle Hayne Limestone		
	Trent Marl		
Mesozoic.			
Cretaceous:			
Upper Cretaceous ...	Pee Dee formation.		
	Black Creek formation		
Lower Cretaceous	Patuxent formation		

Of these only the following are known to contain beds of marl:

Cenozoic.	
Pleistocene..........	Pamlico formation.
	Chowan formation.
Pliocene	Waccamaw formation.
Miocene	Yorktown formation.
	St. Mary's formation.
	Duplin marl.
Eocene	Castle Hayne limestone.
	Trent marl.
Mesozoic.	
Upper Cretaceous......	Pee Dee formation.

CHARACTERISTICS OF MARLS

A marl may be defined in a general way as a calcareous of glauconitic clay or sand. It is impossible, however, to give a strict definition since in popular, and even scientific usage, the term "marl" has been applied to a great variety of soft earthy sediments or weathered rock materials that have been used, rightly or wrongly, for the top dressing of farm lands.

Usually, but not always, lime is present in the form of calcium carbonate or calcium phosphate. Possibly it would be proper to consider any soft rock with from twenty-five to seventy-five per cent of lime as a true marl. Below twenty-five per cent the material would pass into a clay or sand while above seventy-five per cent it would pass into an argillaceous limestone. However, both in North Carolina and elsewhere such an argillaceous limestone if sufficiently uncompacted may be properly classified as a marl.

The lime may be present in a finely divided state or in the form of more or less perfect or fragmentary shells and bones. If the shells constitute a considerable percentage of perfect or but slightly water worn forms the marl is commonly called a shell marl. Shell marls naturally vary through wide limits as to the proportion of calcareous ingredients to clay and sand, and this is notable from locality to locality in beds belonging to a single geological formation.

Thus the Waccamaw marl exposed along the Lower Cape Fear River (Walkers Bluff, Neills Eddy Landing) and in western Brunswick County, may consist almost entirely of shells and shell fragments and analyze between 80 per cent and 90 per cent of calcium carbonate, or the shells may represent such an inconsiderable element as shown in adjoining bluffs along Cape Fear River that the material is practically a pure sand of no agricultural value.

The shell marls of the Yorktown formation which are exposed in a narrow belt extending from Gates to western Beaufort County are similarly made up of shells and shell fragments in a usually sandy matrix.

Shell marls, where the percentage of lime falls below 75 per cent and in which the matrix is sand, are of slight value on the lighter soils of the state that are already too sandy and non-retentive of soil moisture, but may be used advantageously on heavy "black land" where they not only correct the acidity of the soil but greatly improve its texture and physical condition. Similar comment applies to the marls of the Duplin formation which have been utilized for agricultural purposes in Duplin, Sampson, Robeson, Bladen, and Columbus counties.

The marls of the St. Marys formation, on the other hand, while frequently similar to those just mentioned and of admirable quality, more often have the shells and shell fragments embedded in a clayey matrix, as in numerous outcrops in Bertie, Edgecombe, Pitt, and Greene counties. These clayey shell marls, frequently termed blue marls, are not suitable for use on heavy soils since they disintegrate slowly and do not improve the physical character or workability of the soil. On the other hand, they may prove of benefit when applied to light sandy soils naturally deficient in loamy constituents. See Plate XV, B.

The green sand marls found along Tar River, Contentnea Creek, Northeast and Cape Fears rivers, and commonly called blue marls in the area of their outcrop in North Carolina, comprise greenish deposits ranging from clays to sands, containing the mineral glauconite, with or without fossil shells or shell fragments.

Green sand marls were widely used in agriculture in the states to the north of Carolina, particularly in New Jersey, before artificial fertilizers came into vogue. Green sand marls have been found at many geological horizons but are especially characteristic of the Upper Cretaceous and Eocene of the Atlantic states. They sometimes contain as much as 6 per cent or 7 per cent of potash. These so-called blue marls in the North Carolina area are much less rich in glauconite than are the corresponding beds in New Jersey and Delaware, and are largely dark sandy clays. The highest percentage of potash known in any North Carolina deposit is 2.96 per cent, shown by a green sand found on Contentnea Creek about six miles above Grifton.

In general, it may be said that these Upper Cretaceous green sand (blue) marls do not promise satisfactory results and their use is not to be recommended.

The availability of high-grade marls is more or less limited by the transportation problem, but the numerous railroad lines and long stretches of navigable rivers and protected sounds make possible the distribution of the product over a wide area feasible at a reasonable cost.

USES OF MARL

Methods of Use

1. *In Raw State as Direct Surface Dressing.*—In earlier days when slave labor was available quantities of marl were dug directly on the farm or nearby and applied broadcast to the land. With changed conditions after 1865 this seems to have been greatly checked, but at the present time marl is used to a considerable extent, generally, however, without knowing its percentage of lime or without determining the acidity or non-acidity of the land by means of the simple litmus paper tests. The marl is usually dug in the fall of the year from shallow pits when the water table is lowered. It is then thrown out and piled about on the surface to be applied before ploughing in the late winter or early spring. This surface application certainly produces an improved condition of the soil and lasts for a number of years. The improvement produced depends on the amount of available material in the marl and this, as will be seen, varies greatly in different formations and in different areas.

2. *As Ground Product on Land or in Drill.*—Where marl of a high grade is available it is in certain places ground to a fine mealy condition

and either applied directly to the land or used as fertilizer in the seed drill. By the grinding process the fineness of the material makes it more rapidly available for the crop by rendering it more readily soluble. It is more easily distributed through the soil and its mechanical action is more even. Small mills are used on some farms for grinding the product for local use. The larger producing plants use mills of greater capacity for grinding their commercial product.

3. *As Ground Product as Filler for Commercial Fertilizer.*—A certain amount of the highest grade marl is ground and sold to fertilizer companies as a filler to give bulk to their product and to make available a certain desired lime content in special grades of commercial fertilizer.

4. *Miscellaneous.*—Besides the foregoing uses directly on the land for agricultural purposes, marl has other local uses.

In many places the lower grade shell marls have been used in treating the surface of highways and are to a limited extent useful in this way. Lack of wearing and binding power seems in most cases to allow the surface thus made to be easily blown away as it becomes dry and finely powdered by wear. Its use for this purpose does not seem to be increasing nor can it be recommended.

The high percentage of lime in certain marls has made them the subject of experimentation as a source for burnt lime. This does not seem to have proved the expected success where it has been tried. The amount of silica and other impurities in most of the marls would make them of questionable economic use for this purpose.

Some use has been made of marl as an ingredient in the manufacture of Portland cement. Available analyses of marls in North Carolina, however, show that they are not adapted for this use.[56]

Another use made of marl in the past few years has been the neutralization of acid waters from industrial plants. Marl for this purpose should have a very high content of calcium carbonate and be so situated that it can be more economically obtained than pulverized limestone or burned lime.

Causes of Limited Use

1. *Lack of Knowledge and Available Information.*—While there are bulletins advocating the use of marl, these do not apparently reach all the farming population who could make use of them. The tenant farmer especially does not always have the knowledge of the use and availability of marl that he should have to make a successful use of his opportunities. This information could be given wider scope through county agencies,

[56] Eckel, E. C., Portland cement materials and industry in the United States: U. S. Geol. Survey Bull., 522, p. 299, 1913.

especially among those farmers whose opportunity to read is slight. There also seems to be a definite prejudice against locally produced materials, especially where a price is attached.

2. *Limited Occurrence of High-grade Supply at Surface.*—Although many farmers know that their land is underlaid by a good quality of marl, the amount available at the surface or near enough to make digging feasible may be small. The usual information comes to them from surface outcrops or through marl struck in ditching operations. The amount of overburden very largely determines local use of even high-grade marls, for the labor expended in digging may seem to offset any gain from the use of the marl after it is made available.

3. *Shortage of Labor.*—Most of the marl produced for local use must be dug during the late fall after harvesting crops and while the ground is fairly dry so that the water table is lowered. At this season labor on the farm is not so fully employed and extra labor can be obtained.

In the case of the commercial production by the larger plants the labor problem is also very much complicated by the need of farm labor through a large part of the year. Such companies try to produce ahead during the fall and early winter, taking advantage of the excess labor at that time.

The demand for the commercial product is almost entirely limited to the late winter and early spring. Unless production and storage can anticipate this demand the amount of available commercial product is strictly limited by the amount of labor available during the shipping season.

At the present time, owing to the effects of the war, labor in the South as well as in the other sections of the country has become an acute problem, an in the commercial plants labor-saving machinery must be used as far as possible to offset the lack of laborers. During the past season the producing companies could not fill their orders, partly because of labor conditions and partly owing to lack of cars for transportation.

4. *Instability of Producing Companies in Past.*—In the past few years a number of companies have been formed to produce marl in a commercial way. Because of the low-grade product or through various misfortunes of business, most of these have ceased production. Such instability has naturally produced a certain amount of distrust of commercially produced marl and of newly formed companies for such production. The remedy for this is, of course, for producing companies to safeguard the quality of their product in every way and to proceed in their business on the basis of continued orders from satisfied customers; also to form companies to produce marl for an extended period

rather than from the point of view of the promoter. Real business principles applied to developing marl products should stabilize in a great degree the entire problem from the business point of view, and would soon command greater confidence from the consumer.

5. *Ease of Use and Availability of Commercial Fertilizers.*—More than any other cause in reducing the use of marl has been the ease of obtaining fertilizers, especially "special crop" fertilizers. With these delivered at the nearest freight station it has been possible to save much labor and at the same time to provide all the crop requirements at one time. With shortage of labor and increased prices for farm products the farmer cannot be blamed for saving himself all he can in time and strength. The fertilizer acting at once and for definite crops is a better gainer of quick returns. With the greatly increased price of all fertilizers and the difficulty of obtaining certain elements of plant food, marl as a cheap and available dressing is coming again into favor. The demand for it should increase rather than diminish under present conditions.

The problem of using a high-grade ground marl vs. digging and hauling low-grade marl, especially with the present labor shortage, is a live and important one. With the increased use of machinery in handling marl in the commercial plant and the greater demand for labor on the farm for actual crop requirements, it will often be of advantage to the farmer to use the commercial product. He should know the actual cost to himself of digging and hauling the unground marl dug on his own land. He should also know the available amount of lime and phosphoric acid in his local marl and the cost per unit on his land compared with the relative cost of the same elements of plant food in the commercial product when delivered. For this purpose each user should know the analysis of the marl he is using from the local supply and compare this with a good commercial grade. Cases have been noted where a low-grade marl was being used which, when the cost of digging and hauling were added to the fifty cents per ton paid the owner, made the actual return unduly expensive. Such considerations should be taken into account and actual costs computed. One case was observed where a low-grade of Yorktown marl was being used while within a few hundred feet a much higher grade of Trent marl was also being dug and used. The cost of getting each of these to the land was about equal.

Effect of Wider Use of Local Marls on Problems of Transportation

With present conditions of transportation both by rail and water the use of local products is a very great advantage. It should save a great deal in expense to the consumer and mean the release of cars and vessels for other work. With the proper development of commercial marl plants a haul of fifty or one hundred miles would supply a large part of the three areas already mentioned in the eastern part of the state. By the full use of available water routes this might be still further reduced. Any development at the present time which helps to release transportation facilities is certainly a great help toward a successful meeting of the complex problems of reconstruction and rehabilitation which the whole world is facing.

Ideal Locations for Commercial Plants

For Rail Transportation.—A study of the map of the eastern part of North Carolina where marl in quantity is available will at once show the relations between the marl deposits and railroads. There are two centers from which rail lines radiate from water terminals. These are New Bern on the Neuse River and Wilmington on the Cape Fear River. From each of these radiate five or six railroad lines, only one of which is common to the two cities. It is obvious that marl could be shipped by rail from these terminals to all points in the eastern part of the state supplied with rail facilities.

Other available deposits near any of these main lines of railroad could by means of spur tracks or sidings be made available, but not for such wide distribution with as little difficulty.

The vicinity either of New Bern or Wilmington would then hold a special advantage for ramified rail shipments to a considerable part of eastern North Carolina. Other locations would have a consequent disadvantage for diverse shipments over a wide territory.

For Water Transportation—Of those centers available to water transportation New Bern holds an exceptional place. From New Bern it is possible to reach nearly all the eastern counties by water without going outside of protected waters. From the Cape Fear and New rivers recourse must be had to the open sea, and the Pamlico and Chowan rivers, although equally available to protected waters as is the Neuse at New Bern, are not in the region of Eocene or the Duplin marls and have available only the Yorktown or, further up the rivers, the St. Marys marls.

From Wilmington the Cape Fear River and its tributaries furnish inland waterways for transportation for considerable distances. From New Bern the Neuse and Trent rivers also give a considerable length of navigable waters.

Both from rail and water transportation viewpoints then New Bern and Wilmington furnish the best centers for wide transportation of commercial marl products.

MARLS OF THE UPPER CRETACEOUS

The Upper Cretaceous formations of North Carolina comprise the Black Creek formation below and the Pee Dee formation above. The Black Creek formation consists of thinly laminated clays and sands. The latter often have a greenish tinge, but contain only traces of glauconite and are never fossiliferous enough to have a high content of calcium carbonate. Hence this formation is without workable marl.

The overlying and younger Pee Dee formation, as may be seen on the accompanying map, occupies a belt of country extending from Greenville in Pitt County southward into South Carolina and widening toward the southward until, along the Cape Fear River, it has a width of outcrop of about forty miles. Outcrops have been observed in Pitt, Greene, Lenoir, Duplin, Pender, Bladen, New Hanover, Columbus, and Brunswick counties.

The Pee Dee formation consists predominately of compact gray to dark green micaceous and more or less argillaceous sands, sometimes slightly glauconitic and in places carrying thin beds of concretionary masses high in calcium carbonate. The Pee Dee is well exposed in the bluffs along Cape Fear River from Donohue Creek Landing, fifty miles above Wilmington, to near the mouth of Black River. The possibilities of the Pee Dee green sands were discussed at length in Emmons' account of the Agriculture of the Eastern Counties (pp. 91-100) published by the state in 1858. The Pee Dee sand seldom contains as much as 30 per cent of calcium carbonate and usually the amount is much less. They contain traces of phosphoric acid and potash. They also commonly contain considerable pyrites or other salts of iron whose action is deleterious to vegetation. Moreover, the percentage of silica in the form of sand is high, running at times to over 90 per cent.

The shortage of potash throughout the United States since 1914 has led to a vigorous search for new sources of supply. While potash is widely disseminated in the rocks of the earth's crust, it usually forms but a small percentage of their composition. The great extent and thickness of the green sand marls has led to an active interest in and investigation of their possibilities. These marls are found in accessible beds from New Jersey to Arkansas and Texas, and it has been found (See Ashley, G. H., Notes on the Greensand deposits of the Eastern United States, U. S. Geological Survey Bulletin 660 B. 1917) that the deposits richest in potash are those of New Jersey and Delaware, and that the potash content in the green sand marls of Maryland, Virginia, and North Carolina decreases southward. Most of the marls of the Pee Dee contain a trace: A sample from Black Rock Landing on Cape

Fear River showed 1.43 per cent, another from Kinston .23 per cent. The samples richest in this element were from Contentnea Creek near Grifton and three samples showed respectively 1.35 per cent, 1.37 per cent, and 2.96 per cent. The latter sand was especially rich in the mineral glauconite, which in general, a detailed examination of the marls of the Pee Dee formation has shown to be present in very small amounts.

The conclusion is reached that the Pee Dee marls, because of their high percentage of sand, their small amounts of lime, phosphoric acid and potash, and the frequent presence of deleterious salts of iron, are not suitable for marling agricultural land, at least the benefits likely to accrue are not worth the risk of burning or the cost and labor of digging, transporting and applying them. The Acme Fertilizer Co. dig the Pee Dee sand and use it as a filler for commercial fertilizer. Their works are at Acme on the Seaboard Air Line, about 18 miles northwest of Wilmington. Their pits are on the southern edge of the town. The Pee Dee is here a compact greenish sand with a thickness of at least 25 feet, with an overburden of 20-25 feet of sand and Waccamaw shell marl. It is dug by steam shovel and delivered to the mill over a spur track.

The following partial analysis[57] of a sample from this outcrop shows the approximate composition of the Pee Dee as it is developed in the southeastern counties of the state:

Total Phosphoric acid	0.13
Calcium Carbonate	32.04

A complete analysis of a sample from Black Rock Landing as reported by Emmons showed:

Analysis of Peedee Sand From Black Rock Landing

	Per Cent
Silica	38.46
Alumina	6.4
Carbonate of lime	33.4
Phosphoric acid	1.6
Carbornate of magnesia	13.6
Potash	1.43
Soda	2.12
Organic matter	1.6
Water	1.8
	100.41

[57]Dr. B. W. Kilgore, analyst.

MARLS OF THE EOCENE

Two formations of Eocene age are recognized in North Carolina. These are the Trent marl and Castle Hayne limestone. The oldest of the two, the Trent, received its name from the exposures of its strata along Trent River from Trenton to New Bern. It consists of beds of marls, limestones, sands, and siliceous limestones, and was deposited in the Eocene sea which spread a mantle of marine deposits over this part of North Carolina as far westward as Wake and Harnett counties. Most of these more western deposits were almost entirely removed by erosion subsequent to their deposition, and for the purpose of the present study the Trent formation may be considered as occupying a compact area extending from the Neuse River near the mouth of Contentnea Creek to the vicinity of New Bern and southwestward to eastern Duplin and northern Onslow counties. It underlies practically all of Jones County and parts of Craven, Lenoir, Duplin, and Onslow counties, with disconnected patches in Wayne County southwest of Goldsboro.

The limestones and marls of the Trent formation are made up of shells and shell fragments of mollusca, sea urchins, and bryozoa, and may be loose or consolidated into a compact limestone, the "stone" marl of Emmons' report. The latter may be full of shells or these may have been largely removed by solution or replaced to a greater or less extent by silica. Such silicified limestones are commonly known as buhrstones and were formerly utilized for mill stones, for which they are admirably suited. They have also been used as building materials for walls, foundations, etc. They are excellent for such purposes as may be noted in the walls and gate of the cemetery at New Bern which has successfully withstood the weather for over half a century. Trent limestones of this sort may be seen at Spring Garden and Rock landings, and in the Sarpony Hills along Neuse River and at Rock Spring, White Rock Landing, and near Trenton on the Trent River.

Where these hard Trent limestones are not completely silicified but contain a considerable percentage of lime they make excellent road material, a subject that will be referred to on a subsequent page.

These limestones have at various times been burned for lime as southeast of Goldsboro and along Trent River, but they have not proved satisfactory for that purpose.

While the Trent underlies the stretch of country indicated above it is seldom seen except along the larger streams or by digging in the bottoms of the smaller waterways, since the country is usually so flat that it is generally concealed from view by a mantle of soil and subsoil. In respect

A. Marl beds, with overburden and sand removed, ready for steam shovel.—Trent River Marl Lime Company

B. Fifty-ton steam shovel doing the work of fifty men.—Trent River Marl and Lime Company

to the excellence and quantity of the marls, as well as their accessibility, the Trent formation is the most important of any of the geological formations of eastern North Carolina.

The Castle Hayne formation is lithologically much like the Trent formation, consisting of marls, limestones, sands and clays. In general, it is more thoroughly lithified than the Trent and not available for agricultural purposes without grinding. It frequently contains a thin bed of phosphatic pebbles at the base which in any grinding operations would appreciably increase the content of phosphoric acid. It has not been used to any great extent as a marl, although often of admirable quality, but has been extensively utilized in the past as a source of road material around Wilmington. The Castle Hayne formation is found beneath the surficial mantle of soils and subsoils over considerable areas in southeastern Duplin County, central and western Onslow County, eastern Pender County, and northern New Hanover County. Where it is near the surface, as around Rocky Point in Pender County and north of Wilmington in New Hanover County, it is a valuable natural resource that should be utilized to a much greater extent than it has been in the past. It is not as extensively developed or as easily worked as the Trent marls along Trent River, and as a commercial proposition doubtless could not compete with the soft Trent marls, although its lime content is as great and it tends to contain more calcium phosphate, especially in its basal beds.

MARLS OF THE MIOCENE

All three of the miocene formations found in eastern North Carolina contain beds of marl. All are exceedingly variable in composition, ranging from sands and clays of no agricultural value to shell beds of considerable local importance. In no case do the Miocene marls contain as high a percentage of lime as the Eocene marls, and they usually are high in sand or clay, which impairs their value on correspondingly sandy or heavy soils. Marls of this sort when their composition is known, (so that burning by an overdose can be avoided) may, if used intelligently, supply the needed lime to the land, and if at the same time sandy marls are used on heavy land and clayey marls on light sandy land the texture and workability of the land may be correspondingly improved.

The Miocene formations, unlike the older geological formations, do not usually occur in broad sheets, but as scattered remnants of continuous beds which have been largely removed by erosion.

The oldest Miocene found in the state, belonging to the St. Marys formation, is confined to the region north of Neuse River, where it may be expected and is frequently met with in a belt of country covering parts of Northampton, Hertford, Halifax, Bertie, Edgecombe, Martin, Wilson, Pitt and Greene Counties. It has been dug and used broadcast at numerous localities in this belt. In general, the St. Marys marls are of low grade and do not promise much for the future.

The Yorktown formation is found in a similar belt of country lying east of the St. Marys formation and extending into the state from Virginia, where it gets its name from the classic exposures around Yorktown. The Yorktown Miocene is to be expected in Gates, eastern Hertford, Bertie, Martin and Pitt, western Beaufort and Craven counties.

Throughout the greater part of this belt the country is low and large areas are occupied by swamps, under which the Yorktown deposits are too deeply buried to be available. Beds of marl in the Yorktown have been utilized for local marl supplies at but few points and do not promise much for the future. The sand or clay content is usually high and the percentage of lime low, although it is to be remembered that in local areas the quality may run up to unexpectedly high figures. Where labor costs are accurately computed it may be found to be more profitable for the farmer to dig and use a low grade marl from his own land that is accessible, rather than to buy and cart burnt lime.

The Miocene Duplin marl, named from the county of that name, is only found in the country south of Neuse River, where it occurs in detached and widely separated areas of mostly small extent, occupying depressions in the surface of the underlying Cretaceous formations. There are considerable areas in central and western Duplin County and eastern Sampson County underlain by the Duplin marl, as well as a number of areas in western Bladen, eastern Robeson, and northern Columbus counties.

The Duplin marls are generally shell marls of variable composition, and prevailingly sandy, although sometimes solidified to form a sandy limestone as at Lake Waccamaw. They have been utilized locally at various small openings in the areas mentioned with satisfactory results and should be used where they can be dug and applied at less expense than purchased materials from outside the region of their occurrence. Their quality is usually not high and it is doubtful if the best offer any inducement for commercial exploitation.

MARLS OF THE PLIOSCENE

Pliocene marls in North Carolina belong entirely to the Waccamaw formation and are confined to limited areas in the vicinity of Cape Fear River from Walker's Bluff to Neill's Eddy Landing. The formation is believed to underlie a considerable low area in central and western Brunswick County but no outcrops are known or is the digging of any marl reported from that region.

The Waccamaw marls are exclusively shell marls, although thin beds of limited extent may be compact enough to be termed a limestone, as in the region north of Acme. The Waccamaw is prevailingly sandy and frequently lacks shell beds over wide areas. Where the shell beds are found they are lenticular in form and limited in area and are at times almost free of clay or sand, consisting of shells embedded in a matrix of finely broken shells and running from .85 per cent to 95 per cent calcium carbonate, as at the workings near Neill's Eddy Landing.

These marls are often valuable and the extent to which they can be dug with profit depends entirely on the thickness of the area and composition of the beds, their nearness to transportation, and the amount of overburden.

MARLS OF THE PLEISTOCENE

The various Pleistocene formations of eastern North Carolina constistute a mantle of sands, loams, and peat, which is spread over all of the older formations, and forms the immediate surface of the country over practically the whole region from the seacoast westward to the Fall line. The older and higher Pleistocene formations of the western part of this belt are, because of their greater age and elevation, much more dissected by erosion than the lower lying and younger Pleistocene formations bordering the Atlantic Coast. It is only in the latter that shell beds of sufficient lime content to be termed marls are found.

Such shell beds of limited extent may be expected in any of the easternmost tier of counties. The shells are usually not much broken and the matrix is clay or sand that may constitute more than half of the whole. Consequently these Pleistocene marls are generally low grade. They are also dug with difficulty since there is usually considerable overburden and they usually lie near or below tide level.

So far as can be learned the Pleistocene marls have not been dug to any great extent, although some use has been made of them near Belhaven in Beaufort County, at various localities in southeastern Craven County, in Carteret County in the neighborhood of Bogue Sound, near Woodside in Pender County. In southern New Hanover County the shell marl assumes the form of a coquina rock which has been used to some extent for road surfacing, but not, so far as could be learned, for agricultural purposes, although it would be useful as top dressing on farm land after grinding. In a raw state it is probably worthless for this purpose.

MARL RESOURCES OF EASTERN NORTH CAROLINA BY COUNTIES

For the purpose of presenting the local details of marl occurrences by counties eastern North Carolina may be divided into two regions, an eastern and a western.

The first of these comprises the easternmost section of the state, or that part lying east of Chowan River, and a line connecting the head of Albermarle Sound with Pamlico and Neuse rivers and terminating at Bogue Sound in western Carteret County.

This area includes parts or all of the counties of Currituck, Camden, Pasquotank, Gates, Perquimans, Chowan, Dare, Tyrrell, Washington, Hyde, Beaufort, Pamlico, and Carteret.

The surface of the country is a nearly level plain, nowhere rising more than 25 feet above sea level. Much of it is covered with swamps or marshes, of which the great Dismal Swamp is the largest. It also includes many estuaries, sounds, and bays, and there are also a number of lakes in shallow depressions of the surface, of which Lake Mattamuskeet in Hyde County is the largest.

The surface soils and subsoils consist almost entirely of loams, sands, clays, and peaty deposits of the youngest Pleistocene terrace formation. Locally small beds of marine shells are encountered and these Pleistocene surficial deposits are underlain by older marl containing formations of Miocene age, but their cover of younger materials and depth below the level of ground water renders them unavailable under present conditions.

The second area or western section of the coastal plain comprises the tier of counties lying west of the preceding through a belt from fifty to sixty miles in width and bounded on the west by a line drawn across the state from Weldon through Wilson and Lumberton. It includes parts or all of the counties of Northampton, Hertford, Halifax, Bertie, Martin, Edgecombe, Wilson, Pitt, Beaufort, Greene, Wayne, Lenoir, Craven, Jones, Duplin, Onslow, Sampson, Robeson, Pender, New Hanover, Brunswick, Bladen, and Columbus.

This region is covered to a much less degree with Pleistocene deposits and is underlain by formations of Upper Cretaceous, Eocene, Miocene and Pliocene ages containing many marl beds, which in places outcrop directly at the surface. The greater altitude of this part of the state and its consequent more mature topography make the possibility of economically digging the contained marls much more feasible. At the same time considerable areas are swampy, particularly in the southern counties and along the streams, while the flat divides in the interstream areas are often covered with pocosins.

The region is mainly an agricultural one and as much of the land, especially the black lands and those newly cleared, is apt to be sour and heavy. It not only needs the corrective of lime, but also needs the marl to improve the texture or workability of the soil. Even in sandy areas if the marl could be applied in conjunction with the plowing under of green fertilizers, such as some leguminous crop or with applications of muck derived from nearby swamps, the benefit to the farmers of the state would be incalculable.

The majority of the marl outcrops of the state are located in this belt, as is also all of the commercial production. Here marl is of decided economic importance and the reserves available are not only sufficient for supplying the needs of this section for an indefinite period, but also furnishing this much needed corrective to the eastern counties of the state, and to the agricultural region lying to the west, where the Coastal Plain is underlain by non-marl bearing Cretaceous or other formations.

Eastern Section

CURRITUCK AND CAMDEN COUNTIES

The surface of both counties is low and, except for the sand dunes, is a level plain made up of fine sands, sandy loams, and peaty deposits of the Pamlico formation. Limited clayey beds with Pleistocene shells have been encountered in artificial excavations near the Virginia line and similar beds may be expected almost anywhere in the area, but these may invariably be expected to be of small extent and low in lime, and will not repay the labor of digging.

PASQUOTANK AND PERQUIMANS COUNTIES

The surface of both counties is low and level and is made up of fine sands, loams, and peats of the Pamlico formation, except a narrow strip along the western border of Perquimans, where similar materials of the Chowan formation reach elevations of about fifty feet. Pleistocene shell beds of limited extent may be expected almost anywhere in the area but these are likely to be low in lime. A sample of such a marl from near Elizabeth City showed but 26 per cent calcium carbonate, and is not worth the cost of digging and applying to the land. High-grade marl from the Trent River district could be obtained by water transportation, and if used in conjunction with muck dug from the local swamps or with green manure, would prove of value.

GATES AND CHOWAN COUNTIES

The surface of these counties is somewhat higher than that of the preceding counties and is consequently less level and swampy. The soils are similar, fine sands and loams of Pleistocene age. These are underlain by deposits of the Yorktown Miocene, which frequently contain beds of low grade shell marl. Such beds may be encountered in the valley side of Chowan River, but are not likely to prove of great value. So far as known none have been dug east of Chowan River, and what was said in regard to the marl situation in Pasquotank and Perquimans counties applies equally well to Gates and Chowan counties.

DARE, TYRRELL, WASHINGTON, AND HYDE COUNTIES

These counties, with the eastern part of Beaufort, form the peninsula between Albemarle and Pamlico sounds. The whole area is low, level, and swampy, and its surface consists of the sands, loams, and peats of the Pamlico Pleistocene. Low grade shell marls may occur anywhere in these Pleistocene deposits, but their agricultural value is very slight, and high grade marls would well repay the small expense of importation from Jones County.

PAMLICO AND CARTERET COUNTIES

These counties are low and swampy and their soils are similar Pleistocene sands, loams, and peats. Local shell beds may be expected almost anywhere within the area, but their value is slight. No records of the use of such low grade local marls are available except at Newport and along the eastern bank of White Oak River, in the vicinity of Kuhns, where one to four feet of clayey shell marl is often encountered and has been used to some extent, as on the Frog Point plantation, two miles north of Kuhns.

WESTERN SECTION

NORTHAMPTON COUNTY

Northampton is a rolling county, reaching elevations of between 300 and 400 feet in the western part. Much of the surface is made up of discontinuous patches of Pleistocene sands and loams. Lower Cretaceous deposits form the basement of much of the county and these were at one time covered with sands, clays, and marls of the St. Marys Miocene, which were subsequently removed over wide areas by erosion. Remnants of the St. Marys formation are likely to be met with almost anywhere in the eastern half of the county. These frequently contain marl beds of the shell marl type, but none of these are known to run over 35 per cent of lime. They have been used locally to some extent, as at Severn, where analyses showed 33.67 per cent $Ca\ CO_3$ and 0.20 per cent phosphoric acid. These marls are decidedly low grade and of little economic value, but are useful as a soil corrective where they can be obtained at slight expense for digging and hauling. The farmer in applying them can calculate the amount of lime likely to be present as from one-fifth to one-third of the amount of material dug.

HERTFORD COUNTY

The surface is formed by sands and loams of Pleistocene age, underlain by discontinuous deposits of the St. Marys Miocene resting on the deeply buried Cretaceous. The marls of the St. Mary's formation in this area consists of shells and shell fragments embedded in clay or sand. These marls are within working distance of the surface at various localities in the northern and eastern portions of the county along the Meherrin River and along the lower slopes bordering Wiccacon River and Potecasi Creek. The marl has frequently been dug in a small way and applied to nearby fields, as in the vicinity of Lotta, Murfreesboro, and Winton.

Selected samples from along Potecasi Creek are reported to contain as high as 78 per cent of calcium carbonate, but the analyses from a number of localities in the county show a lime content ranging from 33 per cent to 61 per cent, and averaging less than 50 per cent. All the samples show traces (less than 1 per cent) of phosphoric acid. The marl beds are lenticular, of limited thickness, and usually covered with eight to ten feet or more overburden of Pleistocene clays or sands. Nowhere within the county are these marls of sufficient purity, or accessible in sufficient quantities to make them a commercial proposition. Owners having marl beds should, however, make use of them for liming their own land whenever they can be dug without unprofitable expense. When it is recalled that over 2,500 acres of the county are devoted to the raising of peanuts, which receive 500 or 600 pounds of burnt lime to the acre at planting, and 200 to 300 pounds of land plaster (calcium sulphate) per acre later, it would seem that the use of natural marl from local pits in the St. Marys formation or the high grade marl of Jones County, which could be obtained by water transportation, would effect considerable saving.

In describing the deposits in a section six miles northwest of Winton, Mr. John E. Smith[58] states:

"An area of several hundred square miles in this part of the state contains marl beds, many of which have been used locally to supply fertilizer for farm lands. On the farm owned by Mr. G. T. Darden, of Ahoskie, and located on the right (south) bank of Potecasi Creek, navigable to this point, is a deposit showing the following:

[58]Special report to the State Geologist on some lime and marl deposits of eastern North Carolina, by John E. Smith, May 1913.

"GENERALIZED SECTION

e. Clay and sandy clay 10 to 12 feet.

d. Marl, composed chiefly of fossil shells of Pelecypods up to one inch in length, but containing also a few large Gastropods with high spiral coils, and some large Pectens, exposed, 3.

c. Clay, in part blue, with some fossil shells, 3 to 4.

b. Marl, similar to (*d*), but apparently more firmly cemented with calcium carbonate, poorly exposed, 2 to 3.

a. Covered slope to water's edge in Potecasi Creek, 10.

"These beds, except (*e*), are of Miocene age and belong to the St. Mary's formation. They lie horizontally and vary in thickness because of their occurrence in lenses. That they are continuous is shown by the outcrop observed along the banks of Potecasi Creek and its tributaries for half a mile or more and also at a point about three-fourths of a mile south of these banks where, though poorly exposed, they seem to be approximately the same in thickness and constitution.

"The marl in bed (*d*) contains 78.15 per cent calcium carbonate. It is therefore of high quality and is well adapted to use as fertilizer on soils needing the ground or underground form of lime. If a small area of this rock can be found where bed (*e*) is chiefly or wholly removed by erosion it can be utilized on a commercial scale locally and should be extensively used. Such areas are likely to occur on the north slope toward the smaller streams which flow eastward, and along the banks where a tributary joins a larger stream."

HALIFAX COUNTY

The boundary between the Coastal Plain and the Piedmont plateau bisects the county into an eastern half underlain by unconsolidated sands, clays, and marls; and a western half underlain by crystalline rocks, the main line of the Atlantic Coast Line being here the approximate boundary line between the two regions.

Shell marls of the St. Marys formation are widely scattered over the county and have been used sporadically at a large number of localities where they outcrop beneath the Pleistocene cover along the sides of the stream valleys. They have been utilized at times along Quankey Creek near Halifax, along Beech and Fishing creeks around Enfield, at Wrendale and Battleboro, near Tillery and Scotland Neck on the coast line. Near Palmyra, at the sharp turn of the Roanoke, a thickness of seven feet of clayey shell marl is exposed below a cover of nearly sixty feet of sand and clay. Numerous analyses have been made of samples of St. Marys marl from Halifax County. They show a range in calcium carbonate content of from 36 per cent in a sample from Scotland Neck to 87 per cent in a sample from Tillery. In general, the lime content is not above 50 per cent. The content of phosphoric acid in the St. Marys formation in Halifax County appears to be higher than elsewhere in the state, ranging from 1 per cent to 4½ per cent, and undoubtedly due to the abundance of fossil bones in the marl.

BERTIE COUNTY

Bertie County, lying between Chowan and Roanoke rivers, is similar to Hertford County in its geology and surface features. Scattered marl beds of both the St. Marys and Yorktown formation are present in the western and eastern halves of the county respectively. Beds of both have at times been used locally to a limited extent. Several samples of Yorktown shell marl from near Avoca and Windsor have been analyzed. These show traces of phosphoric acid and a content of calcium carbonate ranging from 28 per cent to 63 per cent and averaging about 50 per cent. The overburden is generally heavy, but where the marl is near enough to the surface so that it can be dug cheaply it should be brought into local use.

MARTIN COUNTY

The surface consists of Pleistocene sands and loams underlain in the western part of the county by the St. Marys formation. The surface is low and flat and frequently swampy. The St. Marys outcrops along the Roanoke at intervals from Palmyra to Williamston. No outcrops of the Yorktown are known although both the Yorktown and the St. Marys are frequently met with in wells. The Miocene in this area is predominantly clay or sand. Beds of prevailingly low grade marl are frequently developed, but so far as known no attempts have been made to utilize them in recent years, except in the vicinity of Williamston and Everetts, although many old pits are scattered through the surrounding country. Analyses of samples from these show less than 30 per cent calcium carbonate.

EDGECOMBE COUNTY

The surface is flat and consists of Pleistocene sands and loams. These are underlain by disconnected beds of the St. Marys Miocene which, in this region, consists largely of clays and sands with local layers of marl.

There are many old marl pits around Rocky Mount which have become filled up in the fifty years that have elapsed since marl was dug. Variable St. Marys materials, sometimes marls, outcrop along the Tar River between Rocky Mount and the Pitt County line. Traces of old pits are to be seen around Tarboro and outcrops were noted along Sasnett Mill Branch and along White Oak, Swift, and Long creeks around Wrendale and Battleboro. So far as known no attempts have been made to utilize the marl in recent years. No recent analyses are available, but all the materials seen were high in clay or sand and contained a very low percentage, probably less than 25 per cent, of calcium carbonate.

WILSON COUNTY

Pleistocene sands and loams form the surface of the county. These are underlain by Cretaceous deposits. Beneath the Pleistocene and resting on the Cretaceous patches of St. Mary's Miocene are scattered over the eastern half of the county. Shell marl was formerly dug along Toisnot Creek and Hominy Creek near Wilson, and near Sharpsburg, as well as along White Oak Swamp southeast of Wilson. Available analyses of these marls show a range of from 38 per cent to 72 per cent of calcium carbonate, and in one case 4½ per cent of phosphoric acid. In general, the St. Mary's marls in this region are of small extent and low grade, but where they are readily accessible they might prove profitable for local utilization.

PITT COUNTY

The surface is gently rolling to flat, and ranges from an elevation of 121 feet near the western border almost to sea level along the principal streams. The soils of Pitt County are practically all made up of Pleistocene sands and loams and recent aluvium. These are underlain by Miocene deposits belonging to the St. Mary's formation, except along the eastern border of the county where the Yorktown Miocene lies beneath the surficial materials. Older Cretaceous deposits reach the surface in low bluffs along the Tar and Neuse Rivers, and Little and Big Contentnea creeks.

Shell marls are generally distributed throughout the county at depths of from a few feet to fifty or sixty feet beneath the surface, while green sand marls, which are generally deeply buried, outcrop in the principal stream channels. These marls are usually poor in lime, although local beds may contain small amounts of potash.

As previously mentioned samples from along Contentnea Creek above Grifton show 1.12 per cent to 2.46 per cent potassium and 1.35 per cent to 2.96 per cent potash. Where these green sand marls, often called blue marls, are observed to contain many shell fragments or are bright green in color they may be useful, but no one should go to the expense of digging and applying them without first having an analysis or consulting the State Agricultural Department, since the content of potash is variable and generally low, silica is high, and phosphoric acid and lime are apt to be low.

The marls near the surface are mostly Miocene:—in the southeastern portion of the county belonging to the Yorktown formation and in the western portion of the county to the St. Marys formation. The St. Marys is recorded from numerous localities along Contentnea and Swift creeks.

On the farm of J. P. Dawson shell marl of the St. Marys formation is dug in considerable quantity. These pits are about one-half mile south of the road running northeast from Hanrahan and nearly a mile and a half from the railway crossing at that place. At the time of visit (May, 1918) they were filled with water, but had large piles of marl beside them. When wet the marl has a decided yellowish tinge, but when dry and exposed to the weather it is a light yellowish-white. It is nearly pure shell fragments with great numbers of small bivalve shells (*Mulinia congesta*) as the predominant fossil. The shells themselves are rather crumbly and the almost entire absence of sand makes it a good lime marl for surface dressing.

According to the owner there is about ten feet of overburden consisting of clayey soil and white Pleistocene sand. Below this is about ten feet of the light colored St. Marys marl. Below this is reported a bluish material, possibly Trent formation. Mr. Dawson has one hundred acres or more underlaid with this marl and from the topography there should be large areas of it nearby along Contentnea Creek. The marl is sold at $2.00 per ton at the pile near the pit. The overburden, equal in thickness to the layer of marl, would be rather thick for a commercial development.

Clayroot Swamp.—A drainage project of a canal eight to ten feet deep is being put through this swamp, affording an opportunity to learn something of the underlying strata in this area, the bottom of the canal being ten feet or less above sea level.

The first place visited is a little over a mile below the bridge between Garnerville and Calico. This is in the swamp behind the farm of Mr. Dudley at Clayroot. At this point the dredge struck a hard limestone layer which they broke up with difficulty even with the heavy dredge shovel. This was struck near the bottom of the canal and was about three feet thick. It is in a band running across the canal and was encountered for a distance of about two hundred feet. The material on the bank is hard and fairly compact, bluish-gray weathering to white. The limestone has many particles of a green color resembling green sand, numerous molluscan fossils, some echinoid spines, and abundant bryozoa. The whole appearance of the material is that of the Trent formation.

A mile farther up the canal, at the bridge already mentioned, and for a quarter of a mile east, the dredged canal cut through a considerable stretch of marl. This was struck about six feet from the surface, and the cut went down into it for five feet without reaching bottom.

This marl, as exposed on the bank, is a slightly sandy bluish-gray marl weathering to a grayish-white. A few shells and shark's teeth, with a great abundance of bryozoa, are the characteristic fossils.

Old pits along the side of the cutting show that marl has been dug there in the past. This seems also to belong to the Trent formation.

The shell marls of the St. Marys and Yorktown Miocene are also variable in composition and appearance, ranging fom a bluish-clay filled with rotten shells to the reddish more sandy deposits along the Tar River. See Plate XV, B.

These shell marls were formerly used quite extensively in the county, being usually dug in coöperation or on shares, and many old openings are to be seen around Greenville, Farmville, Winterville, Falkland, Hanrahan, Grimesland, and Pactolus. West of Hanrahan along Little Contentnea Creek, rather extensive deposits of reddish shell marl, such as outcrops along Tar River, can be dug without much trouble from water or heavy overburden. Here the marl is high in lime and low in sand. The lime content and amount of overburden varies from opening to opening and the results of previous analyses show a range in calcium carbonate of from 27 per cent to 82 per cent, the average being between 60 per cent and 70 per cent.

New land should, of course, receive larger applications than that already in cultivation, and dark heavy soils, such as the Portsmouth soils, require more than the light colored Norfolk soils. These latter are the principal tobacco soils in the county and would be greatly benefited by growing some nitrogen collecting leguminous crop, such as field peas, peanuts, vetch, soy beans, or clover, and turning it under before applying the marl. The latter facilitates the decomposition of the organic matter, stimulates the growth of the nitrifying bacteria, and thus increases the amount of nitrates in the soil as well as rendering the potassium and phosphorous more available. In the Portsmouth series of soils the organic matter is already present in the soil and the need of green manuring is obviated unless the soil has been under cultivation for years and its nitrates exhausted.

Farmers should carefully figure the costs of utilizing the local marl deposits as compared with that of purchasing rock lime or high grade ground marl from outside the county.

BEAUFORT COUNTY

The surface of the eastern part of the county and along Pamlico River consists of low flat Pleistocene sands, clays, and swamp deposits, while in the northwestern part of the county and muc south of Pamlico River the surface soils are underlai the Yorktown Miocene which frequently contains ma marls have been dug to some extent around Washing vinity. They are shell marls of somewhat variable cha position and contain from 56 per cent to 81 per cent ca and traces of phosphoric acid. The average lime cont of analyses from different openings is about 60 per cent

Styron Plant.—A lime and fertilizer plant is cond Styron about two miles northeast of Washington. It is and the product must be delivered by wagon over sa marls are dug from an extensive open pit. The ov from six to eight feet in thickness and the marl bed the level of ground water. The marl belongs to the Yor and consists of many perfect shells in a blue clay mat around 70 per cent calcium carbonate, and is ground

Local beds of shell marl are occasionally found in th posits of the eastern part of the county, but these are a local usefulness. Analyses made by the State Departme for J. J. Barnett, of Belhaven, showed 49.58 per cen cent calcium carbonate in two Pleistocene samples. M land of the county is heavy and applications of local s ground marl from Trent River would prove an adm and less expensive than burnt lime.

GREENE COUNTY

The surface of the county is of Pleistocene material lain by Cretaceous. Miocene beds are frequently pres Pleistocene surficial materials and the underlying C St. Marys Miocene in this area is largely sand and quent marly layers. Shell marls are near the surfa Run, near Roundtree, Castoria, and Hookerton. They so far as observed, containing large amounts of sand than 50 per cent calcium carbonate.

Green Sands—There are numerous exposures of the sands along Contentnea Creek, between Snow Hill and are more glauconitic than elsewhere in the state and c tain larger amounts of potash than they usually do th Carolina. The amount is small, however, probably nev or two per cent. There may be present as much as t phosphoric acid and in limited beds where the green san or calcareous concretions the amount of lime may reach

WAYNE COUNTY

The surface of the county reaches elevations of about two hundred feet and the surface is therefore more broken than in the counties lying to the southeast.

Beneath the surficial soils and subsoils, largely of Pleistocene age, the county is underlain by non-marl bearing Cretaceous deposits. The marls which have been encountered at several points represent remnants of Eocene or Miocene preserved in depressions of the Cretaceous surface. Low grade marls of little value belonging to the St. Marys Miocene may be encountered in the extreme northeastern part of the county. Along Falling Creek west of Goldsboro and southeastward in the upland bordering the south bank of the Neuse, outlying remnants of the Trent Eocene have been observed at various points as well is in the southern part of the county around Mount Olive. In the Sarpony Hills unsuccessful attempts have been made to manufacture burnt lime from the Trent Eocene.

Flowers Farm.—On the farm of D. L. Flowers, about 3 miles directly west of Mount Olive, there is a marl pit from which marl is taken for fertilizing purposes. The marl consists principally of a rotten limestone containing many fragments of shells. Casts of bivalves, fragments of echinoderm tests and spines were observed. Lithologically, the material resembles the other Eocene of the region. The pits are located near a small branch. A few feet of surface clays are stripped off and pits are dug to a depth of about 25 feet in the marl. The material is very dry, no water interfering with the digging. After exposure to the air the marl soon crumbles to powder. One pit penetrated through the marl at 25 feet. One pit 23 feet in depth did not pass through it. Near the upper surface the marl is of a light yellowish color, but deeper it is of a very pale greenish color.

Marl has been dug for fertilizing purposes about 3 miles to the southeast of Mount Olive. At the junction of Falling Creek and Neuse River Eocene marl has been dug within the last few years. It consists of calcerous sand, rather firmly cemented in certain places, and containing many fossils, particularly *bryozoans, echinoids,* bones and sharks' teeth. The marl occupies a depression in the crystalline rocks, which are exposed a few rods away. This is the locality referred to by Olmsted in 1827. Similar marl is reported from a few other localities in the immediate vicinity.

These Trent marls are of limited extent in Wayne County. In general, when they are cleanly dug they are high in lime, some analyses running up to 83 per cent, others running off to below 40 per cent. Their average content should be around 70 per cent and as they are for the most part fine grained and soft they can be applied without grinding.

LENOIR COUNTY

Beneath the thin cover of sands, loams, gravels, and swamp deposits most of the area of the county is underlain by the dark greenish or grayish sands and clays of the Pee Dee Cretaceous, which outcrops in bluffs along Neuse River, and sometimes contains thin indurated beds high in lime. In general the Cretaceous of the country is unsuitable for marling.

Along the south bank of the Neuse, a belt of country eight to ten miles in width and extending to the Wayne County line is underlain by the marls and limestones of the Trent Eocene which has also been encountered north of Neuse River near La Grange and Falling Creek. These marls lie at a considerable depth below the general surface of the country but are accessible beneath only two or three feet of cover in the stream bottoms and valley sides. For example, marl is struck along the bottom of Whitely Creek at numerous points and small quantities are frequently used locally. At the Dave Wilkins plantation on Whitely Creek the overburden is 2½ feet. The marl is soft and fine grained and of unknown thickness. A sample analyzed 57 per cent calcium carbonate. A sample collected on the Outlaw Plantation just above the junction of Whitely Creek and Neuse River analyzed 74.05 calcium carbonate and .50 phosphoric acid. The marl bed here has an overburden of two to three feet and showed fifteen feet of soft gray marl without reaching the bottom of the bed.

Along Mill Branch, about four miles south of Kinston, marl has been dug in considerable amounts although in the summer of 1918 the pits were full of water. Here the marl is nearly white in color and consists almost entirely of bryozoa. The overburden is about four feet and the thickness is unknown. The percentage of lime is about 80 per cent.

These marls wherever available are high grade and should be utilized to a greater extent. In conjunction with green manuring or composted with swamp muck they are likely to prove of great benefit to the lighter soils of the county and they can be used alone to advantage on the darker and heavier soils. Care in limiting the amount so as to prevent "burning" is necessary, particularly on light soils.

The State Department of Agriculture has made numerous analyses of these marls from different localities in the county and the majority of these show over 70 per cent of calcium carbonate, and some run as high as 88 per cent.

CRAVEN COUNTY

The surface is prevailingly flat, ranging from tide to 80 feet elevation, and consists of Pleistocene or Recent sands and loams. Fully one-half the area is swamp land and not under cultivation. South of Neuse River and west of New Bern much of the area of the county is underlain by the shell limestone of the Trent formation, which outcrops along Neuse River from Spring Garden Landing nearly to Kinston as well as at many localities along Trent River. North of Neuse River the Trent is replaced or overlain by the Yorktown Miocene which also occupies a considerable area extending along the south bank of Neuse River for several miles above Rock Landing.

The Yorktown contains numerous sandy shell marls which probably occur in isolated areas in the central and northern part of the county, the flatness of the country and the lack of detailed explorations preventing their more exact location.

That part of the county southeast of New Bern lying along and south of Neuse estuary is particularly low and swampy, nowhere reaching elevations of over 20 feet, and containing several large lakes. The surface and underlying materials are all of Pleistocene or Recent age, but contain shell beds at several localities which have been dug for marl. These will be considered first before taking up the older marls of the remainder of the county.

Marl Deposits Southeast of New Bern.—A large amount of marl has been dug from pits on the John L. Roper Lumber Company property, three miles southwest of Riverdale. This is used broadcast on the land. The material consists of a sandy bluish marl with many whole shells of various species and numerous pieces of well preserved coral. At the time visited (May, 1918) water almost completely filled the pits. The section is reported by the agent in charge as follows: loam and sand, 2 to 3 feet; blue-gray marl, 6 to 8 feet, below which more sandy material of a reddish cast is encountered with a great many perfect oyster shells as the main fossils. Both kinds of material were seen in quantity about the pits, but the digging is mainly for the bluish marl. This material has not been analyzed.

On the shore of Brices Creek, about midway between the stations of Croatan and Riverdale, much marl has been dug for local use on the farms of E. S. Ballinger and Noah Caton. This is a similar gray-blue shell marl, but consisting of much finer shell than at the Roper Company's pits. The base of this marl has not been reached at ten to twelve feet, according to report. Digging is possible only in dry parts of the year.

Similar marls have been encountered along Slocum Creek at Mallinson's Point three miles above the mouth, farther up the creek, west of Havelock, and at Shell Slough on the south bank of the Neuse, just above the mouth of Slocum Creek. These Pleistocene marls are exceedingly variable in character and while they are exceedingly useful for use locally in this swampy part of the county they do not possess commercial possibilities.

Township One, (Maple Cypress.) Off the road between Maple Cypress and Hanrahan marl has recently been dug on the farms of J. A. Stokes and Dr. Thomas Faulkner, about three-tenths of a mile southeast of the county line at this point and a little to the south of the road. There are numerous pits on the two farms from which several tons of marl were piled. The marl is a bluish-gray growing lighter in color on weathering, and is somewhat sandy. The pits were full of water at the time of visit, but the following section is reported: About four feet of overburden has to be removed, consisting of loam and sand, after the removal of which marl has been dug to a depth of about nine feet without reaching its bottom. At this depth the water comes in even in dry weather and prevents further digging. This marl is reported to be rather strong on the land and has to be used in moderation.

This is evidently a good marl for local use, and from the general topography of the area there should be a considerable amount of such marl which could be developed here. It is about two miles from the Neuse River and eight miles or more from a railroad. It has numerous fossils and is evidently a part of the Trent formation.

Near Cowan Landing.—South of the main road, just north of the Neuse River, near Cowan Landing (Cowpen Landing according to local authority, on account of the cowpen there from which cattle were shipped), marl has been dug recently on the farm of W. A. McLanhorn. This is a shell marl, with considerable sand mixed with it, according to report, and has been dug to a depth of 18 feet without striking bottom. At that depth water prevents further digging. Four thousand bushels of marl were dug last winter and used on the land.

A similar marl is reported from the farm of the W. C. Brewer heirs adjoining the preceding on the south. This marl, however, grows harder toward the base and can be broken out with difficulty with the aid of a pick. To the west toward Cowan Landing the marl is said to entirely run out.

Biddle Landing.—On the south bank of the Neuse River, at Biddle Landing, and from there eastward to the Maple Cypress bridge marl outcrops on the bluffs along the river. At Biddle Landing the marl is

Rock Landing. The uneven surface of the underlying Trent Eocene rarely reaches the surface in this vicinity and the Trent has not been dug for marl so far as known. Outcrops were observed along the road about two miles south of Rock Landing, and one mile north of Jasper.

The Chemical Lime Company of New Bern.—This company formerly operated a plant in the Trent formation for the manufacture of hydrated lime. This was located on the north bank of Trent River at the mouth of Wilson Creek, about three miles southwest of New Bern and two miles south of the Atlantic Coast line, and the locality is known locally as "Old Mill." This plant is no longer in operation and the following account is taken from a report prepared in the summer of 1913 by John E. Smith for the State Geologist. The quarry shows one to three feet of sandy overburden and eight feet to ground water level of compact porous limestone.

Samples from this quarry were analyzed with the following result:

	Per cent Ca CO3	Per cent Silica (Sand)
Sample No. 1	94.58	4.09
Sample No. 2	89.80	3.74

No. 1 is a vertical section sample composed of fragments taken at vertical intervals of a few inches from top to bottom of the limestone exposed in the quarry. No. 2 was selected as a sample of minimum purity from a large lump of coquina that had been lying on the ground near the kiln for about a year.

Cavities and Porosity.—The surface of the limestone contains many deep conical depressions, caused chiefly by solution of the rock. These cavities are from two to four feet in diameter and vary from one to eight feet in depth. The dissolving waters have removed about half of the former upper surface of the limestone, and approximately one-third of its original volume above the present ground water level below which the conical cavities do not extend.

The interstitial spaces among the fossil shells of the rock are exceedingly numerous and vary greatly in size. They include the convexities and concavities due to the shape of the shells and in many instances the entire interior volume between the two valves of the shell. The amount of this porosity is much greater than is apparent at first sight and careful measurement of selected samples show that 48 per cent of the bulk of the stone is pore space.

This porosity is extremely favorable to thorough and equal distribution of temperature in the kiln and the lime produced by this company was burned in a kiln of the continuous draft type. This rock would doubtless burn thoroughly at the minimum temperature for limestone (1600 to 1700 degrees F.), except for the sand which is a refractory ingredient in the kiln. That the small amount of sand present is not very harmful is shown by the almost negligible quantity of waste matter obtained by sifting the hydrated product in the lime shed.

The specific gravity of this rock is low; 2.21 was obtained as an average of several determinations. Though the samples tested were soaked betwen the times of dry and submerged weighings, there were probably several small air spaces in each that did not fill with water. This would account for the apparent low gravity.

Extent and Quantity.—In 1910 drill holes were bored 100 feet apart each way on 100 acres of this property by W. F. Carlyle. The result of this work, though the figures are not now available, is reported to show limestone in each hole with an average thickness of 21 feet for the entire area, but nearly two-thirds of this is below the level of the ground water. The purity of the stone obtained by this drilling was not determined.

Using the gravity and percentage porosity given above and deducting for solution cavities, it is estimated that there are 8333.06 tons per acre of coquina above the level of the ground water and 1562.45 tons in each acre foot of depth below this level which may be reduced a foot or more by drainage as the exploitation proceeds.

Overburden.—The stone is covered with a light, loose soil containing much fine sand. In several places the rock is at the surface and in some parts of the area the cover is very thin. It reaches a maximum of about three feet where observed and probably does not exceed that in any considerable area. The land is mostly clear but supports small areas of half-grown trees and scattering large ones.

The Plant.—This enterprise was started in 1910 and ground material only was produced the first year. The second year a kiln of the direct continuous draft type was erected at a cost of $2,000. It stands on a brick foundation about 60 feet square and three feet above the surface of the ground. The kiln occupies about one-fourth of the area of this structure, has a diameter of ten feet in the clear, a capacity of 12 tons, and is lined with a wall of fire brick two feet thick. During the third year of its operation the product amounted to 3,500 tons of hydrated lime and the ruling price was $6.50 per ton f. o. b. cars at New Bern. The plant has not been in operation since April, 1912.

Method of Operation.—The overburden was removed with shovels from the conical cavities and placed in that part of the pit from which the stone had been removed. The ledge of coquina was loosened by blasting and broken with picks into lumps of approximately one cubic foot each; these were transported by tramway to the kiln. A total hoist of nearly 30 feet was made by stationary steam power, which also hoisted the quicklime from the kiln to the spreading and mixing machine used in the process of hydration. Slabwood was used exclusively as fuel at the plant. Boats were loaded by hand. If operated on a large scale expense could have been much reduced. The superintendent of a plant of this size could conduct a much larger one with but little additional expense for labor, fuel, etc. The location of the property with respect to the streams is such that one engine could provide sufficient power to load the barges as well as for the operation of the plant.

At the time of the writer's visit (June, 1918) the plant had been allowed to go to pieces and was in a sad state of dilapidation and decay.

Although the plant was not a success in the production of burnt lime, it would seem that the high percentage of calcium carbonate in the rock would warrant its use as a marl. The crystalline character of much of the material would make it less soluble than other nearby marls, even when ground, and the hardness of the rock, necessitating blasting, also is more expensive than a steam shovel proposition. Another thing that mitigates against success is the fact that only about eight feet of the 21 feet of the deposit can be worked on account of the height of the water table at this point. While having possibilities this location does not seem to be in a position to compete with others which are operating farther up the river, in softer material

Thirteen analyses made by the State Board of Agriculture from samples taken at one foot vertical intervals show a range in the calcium carbonate content of from 79.22 to 94.93 and average for the total slightly over 90 per cent.

The only other outcrop of Trent limestone noted was along Trent Road just before crossing Deep Gully, which forms the southwestern county boundary at this point. The materials were poorly exposed and evidently not extensive.

The remaining and by far the most extensive marl outcrops along Trent River are in Jones County, under which heading they will be described.

JONES COUNTY

The surface is made up of Pleistocene loams and sands forming two terrace plains, the lower, or Chowan, occupying the southeastern, and the upper, or Wicomico, the northwestern part of the county. The latter is somewhat rolling because of the erosion of Trent River and its small tributaries, but there are broad inter-stream areas which are very flat and occupied by swamps, the larger being Dover Swamp and White Oak Pocosin.

Beneath these surficial deposits, which contain no marls, there occurs throughout most of the county the marls and limestones of the Trent formation. Only in the western part of the area does the Pee Dee Cretaceous replace the Trent. Neither of these are ordinarily found outcropping at the surface, but they may be seen in stream beds and river bluffs in their respective areas of occurrence, and the Trent, which is the only one that is valuable agriculturally, is extensively exposed along Trent River and some of the smaller streams and may often be reached at slight depths in the valley bottoms throughout most of the county.

Before referring to the various localities in the county where these Trent marls are available for local use, the plants and outcrops of the two commercial plants will be discussed. These are the Trent Marl and Lime Company and the State Plant of the North Carolina Department of Agriculture.

COMMERCIAL PLANTS

Trent River Marl and Lime Company.—This company with offices in New Bern is the largest producer of ground marl in eastern North Carolina. It has two tracts of land, the one now being worked under a royalty at Scott Landing on the west (left) bank of the Trent River at the mouth of Scott Creek. The remainder of the land, which is owned in fee, is on the same bank of the river and on the south side of Scott Creek. In all about two hundred acres are available for production.

The marl quarried consists of a fine-grained coquina overlain by Pleistocene sands usually white in color and a few inches of loam. This overburden is but a few inches thick near the river and at the present workings, 200 yards from the river, varies from 18 inches to three feet. The marl itself is from five to twelve feet in thickness and rests upon the hard Trent limestone, which probably has a thickness of about 30 feet and is underlain by sand. The water table in ordinary weather is about at the level of the top of the limestone and the marl is dug to this level.

The surface of the marl is very deeply pocketed. These pockets in some cases run to the base of the marl and according to report may even penetrate the hard basal limestone. The largest of these pockets exposed was 16 feet in diameter, but usually they are much less in size. Some are funnel-shaped, narrowing downward, or occasionally just the opposite, widening toward the base. In the uncovering of the marl the overburden of loam and sand is removed by hand shovelling, thrown into dump carts and wheeled away. The material in the pockets is dug out by hand and the sides of the pockets made clean by the use of wire brushes so that all foreign matter is entirely removed, leaving the marl clean. In the earlier operations near the mill the marl was shovelled by hand into an endless chain of buckets which conveyed it directly to the mill. At the present time a steam shovel with a capacity of 300 tons per day is used. About half this amount has actually been dug and milled in a day. The marl is dropped by the shovel onto a motor truck with a capacity of two tons which, when loaded, makes the trip to the mill a hundred yards away and delivers its load while a second truck is being loaded. (See plates XI, XII and XIII.)

The truck load of marl is dumped directly onto a coarse screen made of a number of steel rails laid closely together with narrow spaces between. A large part of the material passes through this, the lumps remaining being broken by hand with picks.

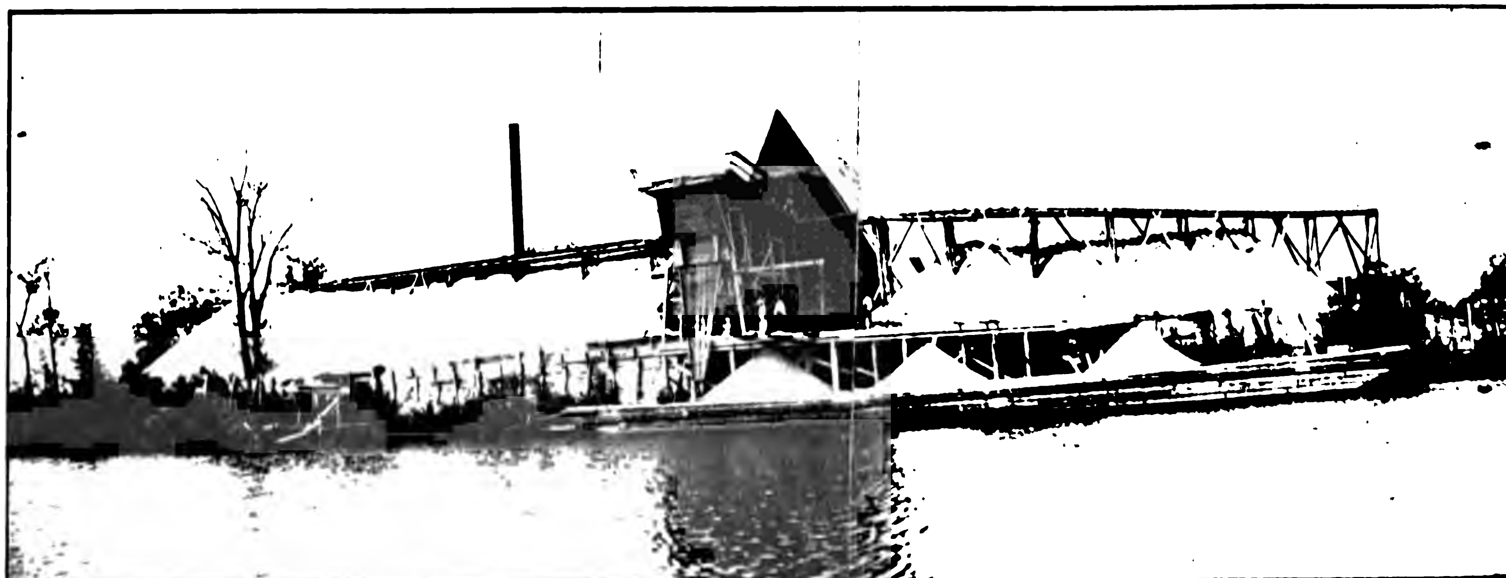
From this rough screen the marl is taken up to two sloping stationary screens by an endless chain of buckets, thence to a four-mesh-to-the-inch shaking screen, from which it passes directly down to the mill. After being ground the product is taken up by another chain of buckets to an overhead runway, from which it may be loaded directly into freight cars by means of movable chutes, or carried to the storage piles or sent out to the end of the runway where it can be sent by chutes directly onto flats or schooners at the landing. At the edge of this landing there is nine to ten feet depth at mean water and 30 feet in the center of the channel but a short distance away. By water it is 12 miles down river to New Bern.

From the plant a standard gauge siding of 2,400 feet connects with the Atlantic Coast Line R. R. at Bowen station, which is 12 miles from New Bern and 79 miles from Wilmington. Cars can be loaded directly from the chutes and pulled out by gravity to a secondary siding.

The ground product is usually sold in bulk but is also bagged, 200 pounds to the bag. Storage capacity at present is about 6,000 tons of ground product, but it is the intention to materially enlarge this. At present the price is $3.50 per ton at the dock or $4.00 f. o. b. at New Bern, but this must soon be increased on account of the increased labor cost. (See Plate XII.)

A 60-horsepower engine is used to run the mill and the various hoists. Water is obtained directly from the Trent River, where a pump is installed. This water is fairly soft, and, except in very dry weather, is not brackish.

There are about 60 laborers employed at the plant and about ten other men in various capacities. The number of laborers is increased to 100 in the winter time and the number is very dependent on the demand for labor on the nearby farms.



End view of Marl Grinding Mills and of 12,000 tons of ground marl ready for shipment by rail and boat.—Trent River Marl and Lime Company.

The past year the plant has been idle for as much as ten days at a time, on account of inability to obtain cars for shipping. As a result orders for several thousand tons of material had to be turned down. The demand for the product is from January 1 to May 1, and production and storage must conform to this short season of demand.

In the field the marl is a creamy yellowish white in color, more or less friable, but on exposure to the air the surface becomes encrusted and whitish. There is very little amorphous material, the marl being almost entirely a coquina with broken shell fragments but almost no complete specimens. About six years ago an attempt to burn the material for lime was made, but on account of the fineness of the marl it was a failure.

Various analyses show a percentage of $CaCO_3$ ranging from 85 to 93 per cent. Sample collected by writer showed 85.22 $CaCO_3$ and .33 phosphoric acid. When dry the ground marl weighs from 70 to 75 pounds per cubic foot.

The limestone underlying the marl is of the typical Trent formation. It is hard, consisting almost entirely of molds and casts of mollusca, both lamellibranchs and gastropods, the former predominating. Teeth of sharks and other animals are occasionally found, according to report. The limestone although porous is hard. It has been used to some extent for road construction on the property, and in the vicinity.

In a region devoid of other road material the hard Trent limestone should prove valuable, particularly since it is available in large amounts and could be quarried in conjunction with the marl and loaded directly on boats for water transportation. A sample tested by the Office of Public Roads of the U. S. Department of Agriculture gave the following results:

Per cent of wear	49.00
French coefficient of wear	0.8
Cementing value	23.00

While the percentage of wear and cementing value are both under the normal requirements for water bound macadam or bituminous concrete, the rock has been used for macadam as, for example, in constructing the Cemetery Road in New Bern and has stood up well under considerable traffic. It would also prove available for use in cement concrete although not so satisfactory as tougher rocks.

Plant of North Carolina Department of Agriculture.—The North Carolina Department of Agriculture is working a marl plant on the Taylor place adjoining that of the Trent River Marl and Lime Company on the north. The marl itself is identical with that already mentioned in the report on the Trent River Company. The deposit is thick, the upper six to twelve feet being worked without reaching the base of the marl. Forty or more acres underlaid by marl remain to be worked. The same pocketing already described is apparent here, but as a rule the pockets seem to be larger than at the Trent River Company's plant.

At present the workings are in a spot where the overburden is from three to ten feet thick, consisting of loam underlaid with Pleistocene sands. This overburden is removed by two scoops on a cable line, the material taken about a hundred yards away and dumped.

The marl in the pit is dug by hand and shovelled into small tram cars drawn by a small steam engine. There are but two of these cars with a two to two and one-half ton capacity, but one of which was in use when the plant was visited. This tramway to the plant is about one-eighth of a mile in length and three foot gauge. The marl is dumped from the car and then shovelled into a conveyor by which it is taken to a shaking screen with a quarter-inch mesh. About 37 per cent of the material passes through this screen, the remainder passing on to the mill, which is a Williams make with a capacity of 100 tons per day. The actual output is about 60 tons per day. From the mill the product is again taken by conveyor up to an overhead trough where by spouts it is put in any part of the storage shed, which is about 30 feet by 120 feet, covered with rubberoid roofing, and with a storage capacity of 1,500 tons. When shipping, the ground product is spouted directly into hand carts of about 500 pounds capacity and these wheeled onto platform scales where they are weighed. They are then wheeled onto the platform and into box cars. The siding which adjoins the Atlantic Coast Line is sufficient for four cars at a time.

The ground marl is sold to the farmers of the state at cost or at $2.00 per ton, f. o. b., in bulk. During the season 5,000 to 6,000 tons are taken out. When a full crew is working 35 to 40 men are employed, but as in the other plant the number of men depends largely upon farming conditions, more men being available in the winter than at any other time.

The machinery of the mill and hoists is run by a steam engine burning coal which can be delivered at the siding.

Shipping is entirely by rail, although the river might be available but would mean a double haul back to the water from the mill. Some difficulty was experienced early in the year in obtaining enough cars, but that has been largely remedied and no serious difficulties are now experienced.

(*Photo E. W. B.*)
A. Working, steam shovel, and motor truck of Trent River Marl and Lime Company

(*Photo E. W. B.*)
B. Side view of the mill of the Trent River Marl and Lime Company

In analysis this marl is about the same as that of the Trent River Marl and Lime Company's marl, averaging 85 per cent $CaCO_3$ in the ground product. The sample collected by the writer showed:

Phosphoric acid	0.15
Calcium carbonate	87.72

In the amount of overburden removed, method of handling and lack of water-shipping facilities this plant is less favorably located than the Trent River Company's plant, but the ground product is essentially the same.

These two plants seem to be the only ones of any size now grinding and shipping marl in a commercial way from the central coast part of the state, and at their present capacity are not equal to the task of filling the demand. Before another season it is probable that the capacity of one or both plants will be considerably increased.

OTHER TRENT RIVER MARL DEPOSITS

Odd Fellows' Property.[59]—This property is on the north side of the river about 200 yards up the river from Mulberry landing. The limestone outcrops in the cliff for a distance of at least 300 feet and is exposed for a thickness of 10 to 12 feet. The rock is very similar to that of the Chemical Lime Company. The overburden is slight, but there has been no development of the limestone back from the river, so it is not known how far this particular bed of limestone will extend.

John Whitford Property.[60]—This property is on the south side of the river and east of Island Creek at its confluence with Trent River. This property consists of 100 acres. Limestone outcrops irregularly along the river for a distance of at least 300 feet. It was also observed almost continuously along the edge of the swamp on the east of Island Creek. At the confluence of a smaller branch with Island Creek hard limestone seems to be more abundant and is found to be almost continuous for about a quarter of a mile. There is considerable variation in the overburden. The rock would have to be trammed from where excavated to barge landing on Trent River, a distance of about half a mile, and this can probably be done by gravity.

That portion of the limestone on the river is somewhat siliceous, many of the shells tested indicating thorough silification. A grab sample was analyzed for lime and silica with the following results:

	Per cent
Calcium carbonate	72.19
Silica	26.05

[59]Reported by Joseph Hyde Pratt, State Geologist.
[60]Ibid.

This property is one of the more promising properties along the river for developing a commercial source of marl and limestone.

DeBruhls Property.[61]—Two and three-quarter miles still further up the river from the John Whitford property, and on the north bank of the river, is the DeBruhls property, which extends for a distance of about 600 feet along the river. This property shows both hard and soft limestone, and a small amount of development work has been done along the river front. In a deep gully to the east of the property but very little limestone is exposed. The land back from the river was tested with an iron rod, but no limestone was encountered. If this portion of the property is underlain by the limestone it is covered by a considerable depth of heavy overburden. This property adjoins the Taylor property that is being operated by the North Carolina Department of Agriculture.

Armstrong Property.[62]—This property is across the creek from the Taylor property and has a frontage of about 200 feet on the river.

Brown Lime Company.[63]—Adjoining the Armstrong property on the upriver side, is a property consisting of 150 acres owned by a Mrs. Simmons and is leased by the Brown Lime Company. It has a frontage of approximately 1,800 feet on the river. There is a good exposure of the small shell limestone of splendid quality along the river front. At a point 600 yards back from the river the same quality is exposed and a small amount of quarrying has been done. (See Plate XVII, A.)

Hardy Whitford Property.[64]—This property is still further up and on the south side of the river about 13½ miles from New Bern. At this point the bluff rises about 20 feet above the river and the fine shell limestone is exposed in the bluff for a distance of about half a mile. Underneath the soft lime rock at a depth of about 10 to 15 feet, and still above ground water, is the hard, coarse shell limestone. The limestone outcrops in the fields back from the river for a distance of at least 200 yards, where it is exposed in the form of a limestone ledge. The limestone outcrops almost continuously up the ravine that extends into the property. The overburden is light.

Similar Trent marl forms a low exposure at Whitford Landing, one-eighth mile below the mouth of Island Creek. Analysis shows 78.32 calcium carbonate and 0.49 phosphoric acid. The underlying hard Trent limestone outcrops along Island Creek Road, one-half mile south of the landing. Similar exposures are found up the Trent River from this point everywhere where the river has cut into the upland.

[61]Ibid.
[62]Ibid.
[63]Ibid.
[64]Ibid.

At a point known locally as Raccoon Landing, on the east bank of the Trent River, about three-tenths of a mile upstream from the mouth of Scott Creek, the same marl is exposed. On the shore there is very little overburden and in the fields back from the river it outcrops directly on the surface in places so that the land cannot be cultivated.

Above Scott Creek About Eigth-Tenths of a Mile.—About eight-tenths of a mile farther upstream where there is a slight re-entrant in the bank a very crumbly marl is exposed, pinkish-white in places, in others grayish-yellow. This is 12 to 15 feet thick in places or even more, resting according to report on the hard Trent limestone below. Parts of this marl seem very pure with almost no sand.

Taylor's Landing.—At Taylor's Landing, one-half mile farther upstream, a similar marl is exposed on the farm of J. C. Brown. This is a crumbly yellowish-gray marl which at the surface at least can be easily dug out with a pocket knife. It has little overburden, shows some evidence of pocketing and has a good thickness as far as could be observed.

The entire east bank of the Trent River from Whitford's Landing to Taylor's Landing shows evidences of excellent soft marls with high lime content. For the most part these can be easily dug. Shipping facilities by water on the Trent River are available and with little expense to utilize. The area underlaid by this marl must be large and from the topography it is probable that the overburden would not greatly increase in thickness except the slight amount due to the probable dip of the beds toward the east. Except for the lack of rail facilities this area appears to be equally as good as that now being worked on the opposite side of the river.

Pollocksville—The majority of the Trent marls are fine materials or porous limestones in which the recognizable shells are those of clam-like mollusca. Around Polloksville a distinct phase of the Trent formation is developed which represents an extensive Eocene reef of gigantic oysters (*Ostrea georgiana*) which are now embedded in a yellow or brown sand. This oyster marl is exposed for several hundred yards east of the Atlantic Coast Line bridge along the north bank of the Trent River, about 100 yards south of the depot at Polloksville, in the bottom of Mill Creek, half a mile southeast of the town, and on the south bank of the Trent River a short distance above the town. At the north end of the Atlantic Coast Line bridge, where the bed is best exposed, it shows an overburden of three to five feet. The marl bed consists of a brownish calcareous sand packed with enormous rotten oyster shells through a thickness of ten to twelve feet. (See Pl. XIV, A.)

As previously mentioned, there is a variable amount of sand present in this bed. Analyses show from 55 per cent to 66 per cent calcium carbonate, and while not so valuable as the other type of Trent marl, it can be used to advantage locally, in the raw state especially, as it is sometimes phosphatic and analyzes three per cent to four per cent phosphoric acid. Farther up Trent River these Eocene marls outcrop northeast and southwest of Olivers in the vicinity of Trenton and near Comfort. Marls analyzed from the properties of T. F. Andrews and W. H. Haywood near Trenton show 34, 44 and 79 per cent calcium carbonate and the more calcareous beds should prove valuable for local uses.

At Comfort the marl is similar to that in the northern part of the county mentioned in the following paragraph, analyzing 88.70 calcium carbonate and in every way a valuable marl.

In the northern part of the county south of Dover a large area comprising much of Beaver Creek Township and extending south through Tuckahoe to Onslow County appears to be underlain throughout most of its extent by materials of the Trent formation. These show considerable variation from opening to opening. Sometimes the material which may be loose or hard contains large amounts of sand. Elsewhere considerable lime has been removed by solution and replaced either with silica or ferruginous salts. The overburden is everywhere heavy except in low land or creek bottoms where it is reduced to from three to five feet. The marl has been used locally to a considerable extent, the practice being to dig it in the dry season after the crops are harvested and scatter it broadcast on the land in the raw state. Much of the land in this region is dark with a tendency to sourness and the marl is therefore a local resource of considerable importance. Samples of the loose marl, such as is used hereabouts, from the property of Lovitt Hines of Kinston, located north of Flat Swamp, showed 73.12 calcium carbonate and 0.66 phosphoric acid.

A similar sample from the adjoining Foy plantation, where the marl is also used to a limited extent, analyzed 64.79 calcium carbonate and 0.31 phosphoric acid. A sample of the hard limestone from the Hines plantation was tested for its availability for road surfacing by the United States Office of Public Roads with the following results:

Specific gravity	2.40
Weight per cubic foot	150
Water absorbed per cubic foot	2.56%
Per cent of wear	10.6
French coefficient of wear	3.8
Cementing value	25.00

A. The oyster bed in the Trent Marl at Polloksville, Jones County

B. Exposure of the Castle Hayne limestone in the quarry near Castle Hayne, New Hanover County

The official values for water bound macadam construction are: French coefficient of wear, five or over, and cementing value, 25 or over. Thus the Trent limestone is low grade for road building and while it would form a good surface it would wear unduly fast. It is tough enough, however, to serve admirably for broken stone or cement concrete foundations and similar work, and in a region without other stone should be used locally where possible.

DUPLIN COUNTY

The surface of the whole county is covered with a thick mantle of sands, loams, and swamp deposits of the Pleistocene terrace formations, beneath which occur in disconnected areas remnants of various older deposits resting upon the Pee Dee Upper Cretaceous, which underlies the whole county except its northwestern portion, where still older Upper Cretaceous (Black Creek sands and laminated clays) replace the Pee Dee deposits.

The only formations likely to contain valuable marls are the Trent and Castle Hayne formations of Eocene age and the Duplin marl of Miocene age.

Marls of the Trent formation are likely to be found beneath a rather heavy overburden in a belt about ten miles in width extending from southern Jones and northern Onslow counties westward to within a couple of miles of Kenansville. South of this belt the Trent is replaced by the Castle Hayne formation in the southeastern part of the county, where it is covered by the Angola Bay or Pocosin.

An area of about 70 square miles in the western central part of the county and extending into eastern Sampson County is underlain by deposits of the Duplin Miocene which frequently contain shell marls that have been worked from time to time.

So far as known no openings have been made in the Trent Eocene for digging marl which here occurs in patches, as previously stated, and generally deeply buried. The Castle Hayne is also rather far below the surface and so far as known has not been used except around the town of Chinquapin, where a sample from the property of G. W. Lamb showed 72.24 per cent calcium carbonate and 2.74 per cent phosphoric acid, and is an admirable marl for local use.

Most of the marls dug in the county have come from the Duplin formation around Kenansville, Faison, Warsaw, Magnolia, and Rose Hill. The Duplin comprises unconsolidated sands, clays, and shell marls. The materials are exceedingly variable, the shell marls consisting usually of broken shells and sand, although in places considerable clay is present and at times the deposits are consolidated into thin beds of sandy limestone.

The great variation in the proportion of sand or clay to shells makes it impossible to predict in advance of analysis the quality of local deposits of Duplin marl, for example, some samples of the marl on the property of W. H. Williams, of Warsaw, showed but 31.07 per cent calcium carbonate while other samples from nearby openings showed 86 per cent. One sample from Rose Hill showed 90.74 per cent. The average of numerous analyses which have been made by the State Department of Agriculture shows 20 to 40 per cent insoluble—mostly sand, and from 60 to 80 per cent calcium carbonate. The Duplin marls generally contain small amounts of phosphate, generally from one to two per cent but at times running up to eight or nine per cent.

None of the deposits in the county offer commercial possibilities but they should be used to a greater extent locally where the cost of digging is not prohibitive.

ONSLOW COUNTY

The coastal portion of Onslow County is thickly covered by Pleistocene deposits, but in the northwestern two-thirds limestones and marls of Eocene age outcrop in places beneath the thinner Pleistocene covering, or are to be found a short distance below the surface. There is little detailed information available regarding the occurrence of marl or other geological data. Certain marls apparently of Duplin Miocene age have a considerable content of phosphate of lime and are excellent for local use.

Belgrade.—Marl has been dug in considerable quantity for local use on the farm of F. C. Henderson. These pits are about one-eighth mile west of the White Oak River, one-half mile in from the road at a point about one-half mile south from the crossing near Belgrade Station. The pits were full of water at the time of visit (May, 1918) and most of the marl had been removed. The section exposed in the pit is reported by Mr. Henderson as follows: Overburden three to five feet, the upper two to four feet made up of a black soil below which is a bluish sandy clay about a foot thick with many roots. The marl is worked to a depth of six to eight feet, at which level water stops deeper digging. The upper part of the marl is fairly loose and contains numerous shells, corals, etc. The lower part grows harder and has teeth and bones with casts and molds of shells, many of the surfaces with blackish irregular (phosphatic) surfaces.

The material has numerous flattened water-worn pebbles up to two inches in diameter. The material becomes hard at the base, and has been blasted to a total depth of ten to twelve feet and seems to grow harder. The marl has been recognized under about 100 acres of this farm, and probably has a greater extent. It is reported on adjoining farms for several miles to the south along White Oak River.

A sample of this marl was analyzed by the N. C. Geological and Economic Survey[65] which gave 56.50 per cent of calcium carbonate and 4.3 per cent of phosphoric acid.

An analysis obtained at the State Agricultural Department by Mr. Henderson gave 37.62 per cent calcium carbonate and eight per cent phosphate of lime.

From available data it seems as if there were two formations present at this locality. There is an upper, softer marl, the shells in which have their color well preserved in some cases and which may be Duplin Miocene. Below is the more compact bluish material in which the sharks' teeth and pebbles are found. This seems to be more like the Castle Hayne than the Trent limestone in its characters, although at the next mentioned locality the characters are more like those of the Trent.

The newly formed Belgrade Phosphate and Carbonate Company has a mill site and siding staked out one-eighth of a mile northeast of Belgrade. It is the intention to erect a mill at this point and grind the blue shell rock as a commercial product. The company has a considerable area under contract, and the mill has arrived at Belgrade. About 100 yards south of the site on the adjoining farm the blue shell rock is exposed in the ditches. There is here an overburden of from two to four feet consisting of soil and gravel, below which is six to ten inches of yellowish-white sand. Below this is the rock with occasional teeth and bones but largely made up of casts and molds of mollusca. This limestone can be broken out with difficulty with the use of a pick. It quickly discolors the water when broken, showing a considerable amount of soluble material. It is proposed to connect this outcrop and that of Mr. Henderson by a tram road with the mill when erected.

Farm of Fred Nelson, Maysville.—On this farm, about three-quarters of a mile above Maysville on the river bank, there are pits about which piles of marl remained from the last season's digging. These pits were full of water at the time of visit (May, 1918). The marl itself is grayish-blue in color, fine in texture, but with great numbers of internal molds of a bivalve mollusk and occasional oyster shells. These molds are very similar if not identical with those found in the limestone at the Chemical Lime Company's plant on the Trent River, four miles from New Bern. At that place, already described, similar molds make

[65]Frank P. Drane, Analyst.

up a large part of the limestone, and the molds at the Maysville locality are equally abundant, although of entirely different color and texture.

According to Mr. Nelson there is about three and one-half feet of overburden and then soft marl down to ten feet below the bed of the river. The river bottom when dry is seen to be composed of this same marl. On the Jones County side of the river Mr. Nelson has about 60 acres which seem to be underlaid by this same marl.

On the river about one-quarter mile above this point Mr. Nelson reports a bed of oyster shells in a sticky matrix, "one shell measuring 26 inches in length." This bed was covered by water and could not be observed, but from the description seems to be *Ostrea georgiana* and similar to the Trent beds near Polloksville. Another bed of these same oysters outcrops about one-half mile farther up the river, according to Mr. Nelson.

Jacksonville to Richlands.—At Jacksonville, at the east end of the bridge across the New River, there is a hard, somewhat gritty limestone with casts and molds of mollusk shells. This is exposed at the side of the road at this point. On the Richlands road from Jacksonville a similar limestone is exposed in and beside the roadway at the crossing of the two creeks, at Chapel Creek and the small creek three miles south of Richlands.

At the bridge over a creek one mile east of the Richlands-Jacksonville road, at the post marked "4 miles to Richlands," marl is exposed in the bank and river bottoms. This is a crumbly limestone with bands of softer material. There are few whole shells, but spines of echinoids are common and a great abundance of bryozoa. The material is light gray in color when exposed to the air, and is very similar to the material already described from the bridge at Clayroot Swamp, Pitt County. The marl is dug and hauled to the land where it is used broadcast. There are old marl pits here and there along this creek where marl has been dug some years ago. It appears to belong to the Trent formation. Analysis of the marl shows 66.49 calcium carbonate and 1.15 phosphoric acid.

Marl is reported on the farm of Sheriff Henderson, one mile northwest of Jacksonville, the overburden ranging from 18 inches to five feet, with about five feet of bluish-gray marl below containing a few shells and some shark's teeth. This is dug each year and spread on the land. It is taken out by a windlass.

Just back from the road three miles south of Richlands, on the farm of H. C. Simmons, on the east side of the road, marl outcrops directly at the surface. This is a very finely granular, mealy, creamy-white marl. Mr. Simmons reports his farm as largely underlaid with this material as are the neighboring farms along the river, on several of which marl is dug and used each year. An analysis of a sample from the property of J. F. Brock shows 88.94 calcium carbonate and 2.30 phosphoric acid. The general character of these marls is shown by the following analyses kindly furnished by Mr. J. K. Plummer through the courtesy of Dr. B. W. Kilgore, State Chemist:

	Calcium Carbonate Per cent	*Calcium Phosphate Per cent*
Richlands phosphate rock	60.62	12.24
Greenbranch shell marl	42.28	4.61
Jacksonville marl	66.49	1.15

SAMPSON COUNTY

The county is covered with loams, sands, and swamp deposits of Pleistocene age underlain by non-marl bearing Cretaceous deposits. Beneath the Pleistocene surficial deposits and those underlying Cretaceous beds are scattered areas of Duplin Miocene, and possibly Eocene, although little is known regarding the details of the geology of the county because of lack of outcrops.

The Duplin Miocene is known to underlie a broad belt in the eastern central portion of the county, which enters it from western Duplin County. This Duplin material extends from the head waters of Six Runs south to the vicinity of Lissa and Taylor's Bridge and westward beyond Clinton to Great Coharie Creek. These Duplin Miocene beds are not everywhere marl bearing, being often clays or sands, nor do they form a continuous sheet but occur in disconnected areas of greater or lesser extent. Marls have been dug to some extent in the past and are recorded from several localities in the district lying between Clinton and Great Coharie Creek.

The Duplin marls are mostly shell marls with a considerable percentage of insoluble sand or clay. They show 40 to 50 per cent calcium carbonate and less than one per cent of phosphoric acid. Samples from Taylor's Bridge analyzed by the State Department of Agriculture show 26 to 56 per cent calcium carbonate and 0.70 to 1.50 per cent phosphoric acid. A sample sent in to the department from Newton Grove in the northern part of the county showed 55.86 calcium carbonate and it is believed to represent an outlying patch of Eocene limestone of limited extent. Similarly another sample from Harrell's Store in the southern part of the county which analyzed 75.69 calcium carbonate probably represents a small isolated patch of Eocene, but whether these two belong to the Trent or the Castle Hayne formation cannot be determined.

In general, it may be said that the marl resources of the county are limited. The marl is usually low grade and deeply buried, except in stream bottoms where water conditions interfere with digging. Where the overburden does not make the digging too expensive the marl should be utilized on the reclaimed swamp lands which cover considerable areas of the county.

ROBESON COUNTY

Beneath the surficial loams and sands of the Pleistocene, the county is underlain by the non-marl bearing deposits of the older Cretaceous. Resting on the uneven surface of the Cretaceous in the southeastern part of the county along the Lumber River and its tributaries, there is found beneath the Pleistocene cover isolated patches of the Duplin Miocene, which here consists of broken shells embedded in a fine sand.

In the past considerable marl was dug and spread broadcast on the land and old pits are to be found around Orrum, Ashpole, Fairmont and Lumberton. The marl is of low grade and contains a large proportion of sand, and while it may still be occasionally utilized locally, most of the old openings have been obscured by time, so that the quality and overburden cannot be determined without more time being spent in the study than the quality of the marl warrants. From the few analyses available the marl appears to run below 50 per cent calcium carbonate.

The Pliocene Waccamaw marl has been dug to some extent around Rosindale (Christopher Moore property) and Councils (Thomas J. Jones and Thomas N. Mausbie properties), about nine miles down the river from Elizabethtown, and northeast of East Arcadia along Steep Run branch and other small streams that have trenched the hills.

The Waccamaw marls are very variable and a shell bed may be replaced by almost pure sand within a short distance. Where a shell bed is well developed it is likely to be thin and have a considerable overburden. The action on the land is also slow unless the marl is ground. This marl has been exploited commercially by B. K. Keith at Neill's Eddy Landing in Columbus County, but this operation has now ceased.

Analyses of the Waccamaw marl, as previously stated, show a wide range in the calcium carbonate content. Those from Bladen County range from 48 to 94 per cent calcium carbonate. Farmers of the county whose land is underlain by shell marl must be guided by the amount of overburden, the local cost of labor, and the quality of the marl as determined by analyses. When these factors are favorable local use should prove profitable, but it is doubtful if any of the marl deposits of the county possess commercial possibilities because of their variability, limited extent and thinness of the deposits.

PENDER COUNTY

Pleistocene sands, loams, and swamp deposits cover the whole surface and except in low bluffs along some of the streams, entirely conceal the underlying formations. Marine Cretaceous beds underlie the whole county. Above the Cretaceous and occupying depressions in its surface in the region lying almost entirely east of the Wilmington-Goldsboro branch of the Atlantic Coast Line R. R. are isolated patches of Eocene marl or limestone belonging to the Castle Hayne formation, and these are in turn overlain in places by thin beds of Miocene. The latter, however, are very insignificant in this region and of no importance as local sources of marl in the county. Along the coast the materials to a considerable depth below the surface are Pleistocene and sometimes these Pleistocene deposits contain shell beds useful as local sources of marl.

The Castle Hayne formation has been reported at scattered points throughout the eastern half of the county. Marl was formerly dug from it on the McMillan property, one mile southeast of Watha, where it appears to be slightly phosphatic and overlain by a few feet of Miocene shell marl. The Castle Hayne has been reported along the valley of the northeast Cape Fear from the vicinity of Burgaw southward.

A considerable area extending from southeast of Ashton through Rocky Point and southward into New Hanover County is underlain by Castle Hayne marl or limestone, which approaches so near the surface around Rocky Point that it is frequently struck in ditches, post holes, and road cuttings. Most of the McRae plantation two miles east of Rocky Point is underlain by Castle Hayne marl or limestone lying but a short distance below the surface.

The overburden consists of from two to five feet of prevailingly "black land" with a high content of humus. The upper layers of the Eocene to a depth of three or four feet are usually fine grained and chalky, and easily ground. The materials become coarser downward, with shell fragments, phosphatic pebbles, and sharks' teeth, and may pass into a hard limestone, or contain concretionary masses of hard partially silicified limestone.

Sometimes the marl and limestone are more or less ferruginized by percolating waters from the dark humus soil and contain numerous limonite concretions. A small mill is used for grinding and the product is used to advantage. None is sold. Analyses show 87.57 calcium carbonate and 0.56 phosphoric acid. The marl is thus high grade and particularly adapted to correct the dark and somewhat acid soils of this section of the county.

Samples of the hard rock from this locality were tested for road surfacing by the office of Public Roads and showed a cementation value of 26 and are therefore suitable for constructing water bound macadam. The amount available for this purpose is not large, however, and could probably not be profitably utilized except in conjunction with the commercial exploitation of the overlying marl for agricultural purposes.

The N. M. McCathrin property, which is about two miles east of Rocky Point railroad station and about three-quarters of a mile from the Northeast Cape Fear River, was examined in 1913 by Mr. John E. Smith of the North Carolina Geological and Economic Survey.

The marl pit on this property showed from 4 to 6 feet of the Castle Hayne marl, similar to that described above, with but one to two feet of overburden. The lower one to two feet of the marl is a hard, dark gray limestone containing phosphate pebbles up to one inch in diameter; while the upper three to four feet is real marl and part chalky. Samples were taken of this particular portion which gave on analysis 88.91 per cent of calcium carbonate and a sample of the harder portion gave on analysis 87.16 per cent calcium carbonate.

This property was also examined by the State Geologist[66] in 1914, who stated that only one pit had been dug on the property which was made at a point about five-eighths of a mile north of Mr. Nixon's house and near the bank of Middle Creek. An area of about 250 feet radius from the pit as a center was examined by means of an iron rod to determine the depth of the marl below the surface. Eight test holes were sunk by means of the rod which showed the shell marl to extend over this area at depths varying from 4 to more than 15 feet below the surface. About five-eighths of a mile up Middle Creek from the pit referred to and about 300 yards southeast of Mr. Nixon's house the marl was encountered at 7 to 9 feet below the surface. This indicated that there is a wide area on this plantation that carries this marl. A sample of the marl taken from the pit was analyzed by F. P. Drane of Charlotte, with the following results:

	Per cent.
Lime, CaO	25.75
Phosphoric acid, P_2O_5	.38
Insoluble (principally sand)	51.45

While this marl will not make a commercial proposition, the material can be used locally with good results.

[66]Report on J. C. Nixon property near Woodside, Pender County, North Carolina, by Joseph Hyde Pratt, for Major W. A. Graham, Commissioner of Agriculture, Raleigh, N. C., November 1914..

Analyses of Castle Hayne materials made by the State Department of Agriculture for French Bros., of Rocky Point, show from 45 per cent to 92 per cent calcium carbonate, and analyses of the lower phosphatic layer show 55 per cent calcium carbonate and 16.42 phosphoric acid.

Unquestionably these high grade marls around Rocky Point should be much more extensively utilized than they have been in the past. None are conveniently located with respect to rail or water transportation or they might find a ready market in the rich truck farming country along the Atlantic Coast Line.

About 1½ miles east of Woodside, on the Wilmington-New Bern branch of the Coast Line, marl has been dug on the property of J. C. Nixon. This shell marl appears to be of Pleistocene age but may represent a loosely compacted phase of the Castle Hayne. At the opening the overburden is 7½ feet. The marl has a thickness of ten feet, most of which lies below the water table. Prospecting shows a considerable area in the vicinity underlain by marl, but nowhere does it approach close enough to the surface to be dug economically. It is also low grade, containing over 50 per cent of sand and 25 to 26 per cent calcium carbonate, and only 0.38 per cent phosphoric acid. It, therefore, has no commercial possibilities, and it is doubtful if it can be dug cheaply enough to even warrant its use locally.

NEW HANOVER COUNTY

The surface of the county ranges from tide to 50 feet elevation and is formed for the most part of the loams, sands, and swamp deposits of the Chowan terrace plain of Pleistocene age. Around the margin of the Chowan in the southern part of the county is a narrow strip of similar but younger materials which are referred to the Pamlico formation. The northwestern part of the county is underlain, sometimes at shallow depths, by the marls and limestones of the Castle Hayne formation of Eocene age, and in limited areas where a depression exists in the surface of the Castle Hayne, thin beds of limited extent represent remnants of Miocene shell marls. The latter are, however, too infrequent and limited to afford a source for agricultural marls and are, moreover, of very low grade.

The Castle Hayne formation, which is the younger of the two Eocene formations known in North Carolina, was named from the exposures in the County Quarry at Castle Hayne. Its materials are variable and comprise marls, limestones, and to a subordinate degree conglomerate layers. The most common phase is a fossiliferous limestone of varying hardness and composition, which has in the past been extensively quarried for road material, both at the County Quarry near Castle Hayne and at the Wilmington City Quarry on Smith Creek. At the City Rock Quarry operations ceased a number of years ago and the old openings are now filled with water. Material from this quarry was used in macadam construction, but it lacks the requisite hardness to withstand heavy wear, although it would serve very satisfactorily for county roads, particularly if surfaced with Tarvia or some similar preparation. The improved streets in Wilmington are now either paved with brick or asphalt. (See Plate XV, A.)

The Castle Hayne in the old quarry has been worked out over an area of about six acres where the overburden was from four to eight feet, and consisted of a total thickness of from 12 to 15 feet of marl, shell rock and pebble rock. Considerable areas in the vicinity are underlain with Castle Hayne although the overburden is from ten to fifteen feet, which is, however, loose sand and easily removed with a steam shovel. The marl is in general too hard to be especially valuable for agricultural purposes without grinding, and lies too deeply buried to be dug profitably, except in conjunction with quarrying operations to obtain road material. Such operations are not likely in the immediate future as the county at the present time possesses no equipment for quarrying.

The County Rock Quarry at Castle Hayne is just west of the highway, eight miles north of Wilmington. The overburden is sand and variable in thickness, ranging from three to twelve feet, and considerable areas worked with convict labor have been worked out in past years. The present small opening, not in operation during the summer of 1918, shows a slight overburden, which has been removed over part of the surface of the limestone. This upper surface is deeply eroded by solution pockets similar to those seen in the Trent formation, but less strongly developed. The limestone is very fine grained, somewhat sandy, contains some sharks' teeth and many bryozoa. It averages about three feet in thickness. Below this is a layer averaging three feet in thickness, a coarse lime cemented conglomerate with many black phosphatic pebbles, and others mixed with them of various kinds and sizes, all showing signs of being water worn. There are great numbers of sharks' teeth in this layer, both whole and broken, although most of them show signs of water wear. Below this conglomerate is a layer of soft, crumbly marl. This is dug out as is also the conglomerate, and carried away by the farmers as dressing for their land. Below the soft layer is another hard layer two feet thick, and below this another layer of softer marl exposed in a small hole blasted in the floor of the quarry. (See Plate XIV, B.)

A. Exposure of Castle Hayne limestone in city rock quarry at Wilmington

B. Marl pit in the St. Mary's formation, nine miles west of Greenville, Greene County

About thirty and one-eighth miles above Wilmington and three and one-quarter miles above Castle Hayne bridge, on the left bank of Northeast Cape Fear River, rotten fossiliferous Eocene rock, similar to certain layers at the Castle Hayne rock quarries, rises seven feet or eight feet above water's edge.

As previously mentioned the Castle Hayne affords in its harder layers satisfactory material for macadam construction where the traffic is light. The interbedded softer layers so common in the formation are too soft for satisfactory road surfacing but useful as a marl. They show a wide range in calcium carbonate content and may run as low as 35 per cent or as high as 75 per cent. The phosphatic pebble layer normally present at the base of the formation analyzes between 50 per cent and 55 per cent calcium carbonate and from six to seven per cent of phosphoric acid, the individual pebbles running as high as 31 per cent phosphoric acid. This material, as well as most of the Castle Hayne marl, requires grinding to make its action as a top dressing for agricultural purposes at all rapid.

It is doubtful if the Castle Hayne marls can be worked profitably under existing labor conditions, but if abundant supplies are available near the surface they should prove useful on the dark soils—those of the Portsmouth series, or those extensive areas of swamp land in the county that only require to be drained and limed to yield profitable crops.

At several localities in the southern part of the county considerable areas of coquina or shell rock are present in the Pleistocene Pamlico formation. The most extensive of these is a bed in Federal Point Township, 13 miles south of Wilmington and one-quarter of a mile west of the Fort Fisher or Carolina Beach highway. The outcrop is about 200 yards wide and extends for about a mile parallel with the highway. The overburden is a coarse to fine ferruginous loam and gravel and varies from two to ten feet in thickness. The coquina is somewhat sandy, of alternating beds of fine and coarse layers, with pebbles, and oyster and clam shells. It is too sandy to constitute a high grade marl and too hard to be utilized without grinding. It is, however, an excellent road material and has been used locally on the county road to Carolina Beach which was completed in the spring of 1917. It appears to stand up well, but would be improved by a tar surfacing. A test made by the Department of Public Roads of the U. S. Department of Agriculture from a sample collected at this quarry showed a cementing value of 29. (See Plate XVII, B.)

Similar Pleistocene coquina rock is exposed along the beach east of old Fort Fisher, and again one mile south of Carolina Beach. In a region where local road materials are so scarce these supplies should be utilized to a much greater extent than they are at the present time.

BRUNSWICK COUNTY

The surface consists of sands, loams, and swamp deposits of the various younger Pleistocene formations. The country is low and large areas of the nearly level surface are occupied by swamps. These surficial deposits are underlain by patches of the Waccamaw Pliocene and the Duplin Miocene, and possibly by a southwestern extension of the Castle Hayne Eocene. The northern part of the county is underlain by the clayey green sands of the Pee Dee Cretaceous. The outlook for available local marl deposits throughout most of the county is not especially promising. Small areas of Waccamaw marl which is found near Acme in the northeastern corner of the adjoining county of Columbus, and is of high grade, may be met with in the northern part of the county in the vicinity of Cape Fear River, or in the southwestern part of the county near Waccamaw River, but none such are known to the writer.

Supposed Castle Hayne limestone has been reported from a number of localities in the eastern part of the county along Old Town Creek and its tributaries, and marl has been dug to a very limited extent in the vicinity of Winnabow and El Paso. So far as known none has been dug in recent years. It is probable that these marls and reported occurrences of Eocene limestone represent the Duplin Miocene. Such, at any rate, was the case in the deposit investigated on the Forks plantation about 3½ miles ten degrees south of west of Brunswick Ferry. Marl was formerly dug here and used broadcast on the land, but none has been used for 15 or more years and the pits are filled with slumped materials and masked by vegetation.

A low ridge six to twelve feet high borders the tidewater swamps along the Brunswick River for upwards of a mile. The Duplin Miocene at several points reaches to just above tide level. At the old opening the overburden consists of five to six feet of sandy loam. The shell marl is of unknown depth and consists of a sandy shell marl with small nodular masses of shell limestone.

Analysis shows 87.57 per cent calcium carbonate.

BLADEN COUNTY

Beneath the surficial Pleistocene loams and sands the whole county is underlain by Cretaceous deposits. Limited areas where Miocene or Pliocene beds are present in isolated patches between this underlying Cretaceous and the overlying Pleistocene occur at a number of points south of Cape Fear River and occasionally outcrop in stream bottoms where the country is broken.

The Duplin Miocene with sandy shell marls may be expected in the area south of the river from Tar Hill to a few miles below Elizabethtown and southward beyond Abbottsburg and Clarkton. The similar sandy shell marls of the Pliocene Waccamaw formation are found between Rosindale and Cape Fear River and north of East Arcadia. The outcrop on the river at Walker's Bluff, where a high grade shell marl shows a thickness of five to ten feet and is overlain by about 15 feet of sand and clay.

The following notes on marl in Bladen County were made by Mr. John E. Smith of the North Carolina Geological and Economic Survey during the summer of 1916:

"Some prospecting for marl has been done on the farms of Miss Anna Guion Stith and Mr. C. W. Lyons, about three miles northeastward from Dublin on the right (south) bank of the Cape Fear River.

"There is a landing on each of these and the bluff here is three hundred yards or more from the river. This bluff reaches a height of nearly one hundred feet and varies in gradient from nearly vertical to very gentle slopes.

"An outcrop of shell marl was found at or near a location known as 'Oyster Shell Ridge' on Miss Stith's farm. The unweathered rock of the stratum was not exposed but the loose material covering it on the hillside indicates a total thickness at this place of probably six feet of good shell marl. The samples obtained showed the presence of 65 per cent to 70 per cent of a $CaCO_3$ which is probably much lower than would be shown by tests of material taken directly from the marl bed. Among the fossils observed are Pelecypods, Gastropods, Brachiopods, Bryozoans, etc., part of which are well preserved, but most of them are fragmental.

"The position of the marl bed is well toward the top of the bluff and pits would be easily and thoroughly drained in working it. The deposit lies beneath five to twenty-five feet of sand and clay, on which heavy timber stands, and therefore could not be exploited profitably in small areas unless larger ones are found; these a considerable search along the bluff failed to reveal. Several occurrences of marl along the creeks in this vicinity and one or more along the road to Lumberton are reported."

What was probably Duplin marl has been dug on the Clark property four miles southeast of Elizabethtown. It has been dug from time to time for local use without grinding and is reported from the Pierce property, two miles northeast of Clarkton and along Brick Yard branch, four miles south of Clarkton.

Marl is also reported at various localities in a belt extending along the tributaries of White Marsh Creek from about four miles north of Clarkton southward to Whiteville in Columbus County.

The analyses available from the records of the State Department of Agriculture show considerable variation in quality and a range of 44 to 94 per cent calcium carbonate.

COLUMBUS COUNTY

The surface is formed by the sands, loams, and swamp deposits of the Wicomico and Chowan Pleistocene formations. The Wicomico is the higher, better drained, and more rolling of the two and reaches elevations of upwards of 80 feet. It forms the northern and western parts of the county. The Chowan is lower, occupies the southern and eastern section of the county, and contains broad areas of swamp land. The Pee Dee cretaceous underlies the whole county beneath the thin mantle of these Pleistocene formations. It contains no marls of agricultural value, although large amounts of the Pee Dee materials are utilized by the Acme Fertilizer Company as a filler for commerical fertilizer.

Beneath the Pleistocene mantle and occupying depressions in the surface of the Pee Dee cretaceous shell marls of the Duplin Miocene and Waccamaw Pliocene are often encountered. These usually are present as thin beds of shell marl or rock, and may be met with in any part of the county, although none are reported from the southern half of the county. The Duplin formation outcrops along the north shore of Lake Waccamaw and underlies a considerable area northeast of the lake.

The outcrop on the lake shore and in adjoining gullies shows two to ten feet of ferruginous sandy clay of Pleistocene age, beneath which is an eight foot bed of Duplin marl, consisting of broken shells embedded in broken shells and sandy clay. Beneath this there is a four foot bed of compact shell limestone. The upper bed of shell marl has been found near the surface at various localities in the vicinity of the Florence Branch of the Atlantic Coast Line R. R. from the vicinity of Bolton westward as far as Fair Bluff and has been dug sporadically and spread broadcast on the land at various localities near Bolton, Whiteville, Chadbourne and Fair Bluff. It is of low grade and usually too sandy to be useful except on heavy clay soils. Analyses of several samples show a varying calcium carbonate content ranging from 30 per cent to 60 per cent. The shell limestone underlying the marl in the vicinity of Lake Waccamaw contains traces of phosphoric acid and 55 per cent calcium

A. Marl pit in the Duplin formation, one mile east of Magnolia County

B. Exposure of limestone of the Duplin formation, north shore of Waccamaw Lake, Columbus County

carbonate. As it is deeply buried, except along the lake shore, and would require grinding to be of use, it is not to be recommended as a source for agricultural lime. (See Plate XVI, A and B.)

The Waccamaw Pliocene contains local deposits of shell marl of high grade, but usually of slight extent and thickness. It underlies considerable areas in the vicinity of Acme (formerly Cronley) in the eastern part of the county. It overlies the Pee Dee Cretaceous in the workings of the Acme Fertilizer Company at Acme but is only a few inches thick and is not utilized. It occupies a number of small basins northeast of Acme in the vicinity of Neills Eddy Landing on Cape Fear River and was formerly worked commercially by B. F. Keith Here the country is timbered and the overburden heavy, ranging from five to fifteen feet. For ten years or more prior to 1913 operations were carried on. The marl varied slightly in quality, analyses made for Mr. Keith by the State Department of Agriculture showing from 65 to 95.83 per cent calcium carbonate, and the ground product 85 per cent. Sample collected by the writer in 1918 showed 0.46 phosphoric acid and 77.96 calcium carbonate. On account of the heavy overburden the plant was moved to a locality about one-fourth mile south of Greenbank Landing.

The overburden is shoveled into small cars that run on a tramway and is dumped into the pit filling it at some distance back from the face of the marl, as progress in excavation is made. The marl is easily loosened with picks and no blasting has been done. Pits have been opened at various distances not exceeding 500 yards from the crusher, to which the marl is transported in a tram car, (capacity, half a ton) drawn by a mule. As the crusher is of the swinging hammer type, the marl must be thoroughly dried before reaching it; this is accomplished by means of the method known as the American process. A hollow tube 22 feet long and about two feet in diameter is mounted in such a way as to permit rotation while the lumps of marl are passing through it. This tube is placed between a brick furnace and a smokestack, with the furnace end about three feet lower than the other, and conveys a direct blast of heated air from the furnace to the smokestack. The marl enters this revolving drum at the upper end and passes in three minutes to a conveyor at the lower end that transports it to the crusher. The capacity of the dryer is eight to ten tons daily. Power for all of the machinery is supplied by a 15 horse power gasoline engine.

The ground marl is stored in a bin as it leaves the crusher. From the bin it is put into bags of 200 pounds each, and transferred to lighters (capacity 60 tons each) on the river only a few feet away. At Wilmington it must be reloaded, and is sold for $7.50 to $9.00 per ton f. o. b. cars. This lime is used as a soil amendment.

The mill is usually in operation from September or October to April or May, but in 1913 did not begin until late in November, when it was installed in its new location. The annual output varies from 600 tons to 1,000 tons, and when the plant is run at full capacity about 15 men are employed.

A. Working Marl deposits with hand labor

B. Exposure of Pleistocene coquina rock, New Hanover County

PART IV

NORTH CAROLINA'S POSITION IN THE MARBLE, LIMESTONE AND LIME INDUSTRIES

Introduction

The unfortunate position of North Carolina and South Carolina with respect to the great limestone resources of the country is shown in Plate 1. The great series of extensive limestone and dolomite formations of the Appalachian Mountains passes southwestward through Virginia and West Virginia, across eastern Tennessee within a very short distance of the North Carolina boundary, across the northwest corner of Georgia and into central Alabama. Only a few relatively small outliers of this great series are found in western North Carolina, and besides these there are only small deposits, mostly of inferior quality and unfavorable location, in the western half of the State, and marl or shell rock deposits, most of which are also inferior, in the eastern part.

So far as the actual tonnage of limestone in the more important deposits is concerned, the state's resources are considerable, but their restricted distribution and distance from large markets compared with the more widely distributed deposits of the other states further limits their industrial importance.

The first table below, compiled from reports of the State Geologist, shows the comparatively small total value of marble, limestone, and lime produced in North Carolina since statistics have been available, and later tables show the corresponding total values of limestone and lime produced in adjacent states during recent years.

Total Value of Marble, Limestone, Marl, and Lime Produced in North Carolina 1898 to 1918, Inclusive

1898	$ 1,155	1904	$ 19,887	1910	$ 77,585	1916	$ 176,164
1899	300	1905	29,015	1911	81,651	1917	233,950
1900	------------	1906	72,051	1912	100,766	1918	220,407
1901	8,266	1907	46,338	1913	140,364		
1902	23,153	1908	53,405	1914	154,888		
1903	25,365	1909	106,931	1915	164,346		

The production of marble and limestone (including marl) in North Carolina, compiled from reports by the State Geologist and the U. S. Geological Survey, is shown in the following tables, in as much detail as available data permit:

LIMESTONE (INCLUDING MARBLE AND MARL) SOLD IN NORTH CAROLINA, 1898* TO 1918, INCLUSIVE.

	Monumental Marble and Building	Furnace Flux		Crushed Stone		Agriculture‡	
		Long Tons	*Value*	*Road Metal Value*	*Concrete Value*	*Short Tons*	*Value*
1899	$ 300		$	$	$		$
1900							
1901	237†			4,668			
1902				21,063			
1903	4,365						
1904	2,741			12,088			
1905				16,500			
1906				30,583			
1907	*13,328			9,000			
1908	8,175			¶			
1909	22,783			¶			
1910	16,875			¶			
1911	14,230	10,000	5,000	15,578			9,700
1912	17,292		7,650	10,294			29,570
1913	25,394	18,781	11,269	15,174	339		40,350
1914	51,400	15,701	10,552	8,685	1,075		38,442
1915	52,937	24,000	17,000	6,388			59,284
1916	¶	¶	¶	¶	¶	46,032	65,101
1917	¶	¶	¶	¶	10,631	67,415	95,288
1918	¶	¶	¶	¶	¶	32,365	87,889

*The only sale reported in 1898 was riprap valued at $450.

†In 1901 a value of $237 was reported by the State Geologist for limestone sold for building. No marble was sold in that year. The value for 1907 also represents rough limestone.

‡The figures to 1916, inclusive, include marl. Marl production in 1917 and 1918 shown in another table.

¶Less than three producers. Figures withheld to avoid disclosure of confidential information.

MARL SOLD IN NORTH CAROLINA IN 1917 AND 1918*

	Quantity (Short Tons)	Value	Average Price Per Ton
1917	11,728	$29,261	$2.49
1918	29,634	86,585	2.92

*Production prior to 1917 included with that of pulverized limestone in the preceding table, or in that of lime on page 000.

MARBLE

Activity in developing marble quarries in North Carolina has been intermittent since 1900, if not earlier, but in no year have sales been made by more than one company. During this period marble quarrying has been an important industry in the neighboring states of Tennessee, Georgia and Alabama. Its annual value during recent years has averaged about $1,000,000 in Tennessee and Georgia, and the marble has been sold throughout a great part of the country. The marble deposits of North Carolina are less favorably situated so far as freight rates are concerned, but this is probably not the main factor retarding development, as marble of superior quality and attractiveness has been marketed throughout the country in spite of high freight rates and long hauls. Most of the marble thus far prospected in the state has been too much fractured to be quarried economically, and no more attractive than marbles well established in the trade. The stone quarried by the Regal Marble Company, at Regal, Cherokee County, is a partial exception to this rule, as it is in part different in appearance from any other marble quarried east of California, and has found favor as a monumental stone. At a few other places in Cherokee, Macon, and Swain counties marble of sufficient quality to merit development has been found, some of it resembling marble quarried in Georgia and some of it of unusual if not unique color, but, all things considered, North Carolina is not destined to become an important marble-producing state.

The following notes on development are taken from the State Geologist's reports on the mining industry in North Carolina from 1900 to 1912 inclusive:

In 1900 the Notla Marble and Talc Company was active a large part of the year at the Kinsey quarry, 5 miles southwest of Murphy. Four channelers were in operation and some splendid blocks of marble were taken out, but no sales of marble for building or monumental work were reported during that year or subsequent years. The only sales reported from this quarry have been for flux.

The Culberson quarry, to the southwest and near the North Carolina boundary, was under development about the same time. No sales of marble have ever been reported from it, however, although some waste stone may have been sold for flux.

At Regal, 3½ miles northeast of Murphy, development work began probably in 1902 and sales of monumental and building stone were made in 1903 and 1904. No production was reported during the next three years, but sales have been made in every subsequent year, from 1908 to 1918.

In 1907 efforts were begun to interest capital in marble deposits in Swain County, and during the following 2 or 3 years the North Carolina Mining and Talc Company did some development work. Some blocks were quarried for exhibition purposes, but no sales of marble were reported at that time or in subsequent years.

Prospecting for marble at other places in Cherokee and Swain counties has taken place at different times, but there have been no developments comparable with those mentioned in the preceding paragraphs.

All of the other limestone deposits described in Part II of this report are crystalline and may be termed marble, from the strictly geologic standpoint, but very little of it would meet the commercial requirements of marble.

LIMESTONE

Present Uses

The production of limestone, including marble for flux, and marl or shell rock for road metal, has increased from practical insignificance in 1900 to a total value of more than $100,000 in 1917; but this value, as shown by the accompanying table, has been much less than that of any other southeastern state except Georgia and South Carolina. Georgia has an abundant supply of limestone in its northwest corner, between the productive districts of Tennessee and Alabama, which limit its markets in these states, which are nearer than markets, other than agriculture, within its own area. Deposits in South Carolina are even fewer than in North Carolina.

TOTAL VALUE OF LIMESTONE IN CERTAIN SOUTHEASTERN STATES, 1913-1918, INCLUSIVE

	1913	1914	1915	1916	1917	Principal Uses
Alabama	$ 812,664	$ 787,214	$ 426,266	$ 917,599	$ 1,278,908	Mostly flux, considerable crushed stone, also building, agricultural and riprap.
Florida	156,589	343,799	354,673	479,837	494,568	Mostly crushed stone; also agriculture and building.
Georgia	83,899	89,216	86,254	82,799	155,172	Agriculture and crushed stone.
Tennessee	643,586	678,068	855,245	752,649	750,639	Mostly crushed stone; considerable flux; also agriculture and riprap.
Virginia	598,032	1,194,261	1,534,545	1,062,247	1,263,284	Mostly crushed stone; considerable flux; also agriculture.
West Virginia	1,046,625	778,749	922,766	1,452,393	1,788,528	Mostly flux; also crushed stone and comparatively little for agriculture.

North Carolina's increase in the production of limestone has been due mainly to the marked increase in pulverized limestone for agriculture. This has been a rather important product in the neighboring states, but very subordinate to crushed stone and flux in all except Georgia. North Carolina's value of pulverized limestone sold has exceeded that of most of the other states, even Virginia and West Virginia, in some years.

Flux.—The flux represented in the accompanying table was mostly waste, sold to furnaces and smelters in southeastern Tennessee, from the marble quarries in Cherokee County, principally the Kinsey quarry. A small quantity has been sold during the past year or two by Clinchfield Lime Company, Asheford, to open hearth steel plants. Quarries of fluxing stone in Cherokee County must compete with quarries in northen Georgia and southeastern Tennessee, and it is significant that no quarries in that county or elsewhere in North Carolina were worked for flux in 1916 to 1918, although the demand for copper and iron was unusually great. Either more suitable stone can be obtained elsewhere, or satisfactory stone can be quarried more economically elsewhere now, that the supply of waste marble and stone above water level at the Kinsey quarry has been largely exhausted. Stone to be suitable for flux should contain very little silica and alumina, or "insoluble" (preferably 2 per cent or less), should be practically free from phosphorus and sulphur. Both high calcium and high magnesium or dolomitic stone is satisfactory, each being preferable in certain particulars. Of the 37 limestones represented by analyses tabulated on pages 149-151 only 14 are sufficiently low in silica and alumina to receive very favorable consideration. Of these the dolomite marble in Mitchell County (analyses 19 and 20) is by far the best. It is on the line of the Carolina, Clinchfield & Ohio Railroad which connects it with industrial centers in northeastern Tennessee. Anaylsis No. 31 is also unusually low in "insoluble," but is probably not an average of the rock quarried, and is much more distant from metallurgical centers.

Crushed Stone.—The crushed stone sold from 1901 to 1910 was mainly if not wholly shell rock from New Hanover County. Craven, Columbus, Beaufort, and Jones counties also furnished this material during the next few years, but very little of it is used at present. An intermittent production of crushed dolomite began at Hewitts' in Swain County in 1912; more steady production began at Fletcher, Henderson County, in 1912, and at Asheford (Linville Falls Station), McDowell County, in 1916. These three quarries have railroad connections and are equipped to supply a considerable demand. The low price of crushed stone, however, and the availability of granite in the central parts of North Carolina and South Carolina partially limit their markets to the western parts of these two states, where large cities are few.

The results of physical tests on limestone and dolomite made by the Bureau of Public Roads, U. S. Department of Agriculture, are given in the table below.[67] In the table the term marble implies crystalline high calcium limestone. The weights per cubic foot of the marbles are very close to the theoretical weight of pure calcite, and signify a general absence of pore space, which is also indicated by the low degree of absorption. Of the dolomites that marked "Hewitts, Macon County" (probably from Swain County as it was shipped from Hewitts, Swain County) has almost the theoretical weight per cubic foot of pure dolomite. The others are not quite so heavy, probably because of the small percentage of calcite present.

The high calcium rocks show a somewhat higher percentage of wear (a lower French coefficient of wear) than do the dolomites, and are hardly suited for more than light traffic (less than 100 vehicles a day). That of the dolomites, however, is for moderate traffic (100 to 250) vehicles a day) on water-bound macadam and for moderate to heavy traffic on bituminous roads. The same remarks apply to the tests for hardness and toughness, which, so far as available, compare favorably with the average for limestones, dolomites, and marbles in the country. Test No. 8,295 is rather unusual, showing a comparatively high coefficient of wear, but inferior hardness and toughness. Only three of the tests show more than low cementing values.

[67]Hubbard, P., and Jackson, F. H., The results of physical tests of road-building rock: Dept. of Agriculture, Office of Public Roads and Rural Engineering, Bull. 370, pp. 6-12, and 51-53, 1916; also, The results of physical tests of road-building rock in 1916 and 1917: Bull. 670, p. 15, 1918.

RESULTS OF PHYSICAL TESTS OF MARBLE (CRYSTALLINE LIMESTONE) AND DOLOMITE FOR ROAD-BUILDING ROCK

Serial Number	Town or City	County	Name of Material	Weight per Cubic Foot Pounds	Absorption per Cubic Foot. Pounds	Per Cent of Wear	French Co-efficient of Wear	Hardness	Toughness	Cementing Value
3,383	Andrews	Cherokee	Marble	172	.16	6.0	6.7	14.1	3	61
6,199	Murphy	Cherokee	Marble	172	.28	4.4	9.1	14.7	6	21
6,196	Regal	Cherokee	Marble	171	.06	4.7	8.5	14.0	4	21
11,507	Regal	Cherokee	Marble	169	.25	6.06	6.6	12.3	3	*
6,977	Hewitts	Macon	Dolomitic marble	181	.21	6.0	6.6	15.2	10	9
8,295	Hewitts	Swain	Dolomite	178	.34	3.9	10.3	12.5	3	39
504	Hot Springs	Madison	Dolomite	178	.13	4.2	9.5	*	*	*
772	Hot Springs	Madison	Dolomite	178	.22	5.5	7.2	*	*	21
868	Marion (Woodlawn)	McDowell	Dolomite	175	.27	4.7	8.6	*	*	21
11,397	Asheford	McDowell	Dolomitic marble	178	.41	4.5	8.9	16.0	8	25
4,963	Asheville (probably quarried at Asheford, McDowell County)	Buncombe	Dolomite			4.0	10.0	17.3	14	18
Average limestone and dolomite in United States				Limestone, 168; Dolomite, 170			8	15	7	Less than 25
Average marble					173			14	5	Less than 25
Requirements for water-bound macadam				Light traffic		5 to 8	5 to 8	10 to 17	5 to 9	Less than 25 low
				Moderate traffic		2.7 to 5	8 to 15	above 14	10 to 18	26-75 average
				Heavy traffic		below 2.7	above 15	above 17	above 18	Above 75 high
Requirements for bituminous roads				Light to moderate traffic		Not over 8	5		5	
Broken stone with bituminous carpet or bituminous broken stone with seal coat†				Moderate to heavy traffic		Not over 5.7	7		10	
Bituminous concrete with or without seal coat†				Light to moderate traffic		Not over 5.7	7		7	
				Moderate to heavy traffic		Not over 4	10		13	
Requirements for Portland cement roads†				Moderate traffic				12	Not less than 8	
				Heavy traffic				16		

*Test not made.

†Light traffic implies less than 100, moderate traffic 100 to 250, and heavy traffic more than 250 vehicles a day.

Agricultural Limestone.—The use of pulverized limestone as a fertilizer or soil amendment has increased rapidly during the last ten years, increasing six-fold from 1911 to 1916. North Carolina's production has made even greater increase during these years, and has continued to increase during 1917; but there was a marked decrease during 1918, owing to adverse conditions of transportation during the war.

The figures for years prior to 1917 include a certain quantity of marl, but this product is shown separately for 1917 and 1918. Marl at present is produced by the State Department of Agriculture, the Trent River Marl Co. and a few others who produce for local use. It is probable that some small quantities dug occasionally by farmers at various places for their own use are not included in the figures of production. The production in 1918 increased considerably over that of 1917, but not enough to offset the decrease in pulverized limestone.

The great majority of the marl deposits of the state, as shown by Berry and Cushman in Part III, are too low in lime content and too unfavorably situated to be of more than strictly local interest. Only those near New Bern and Wilmington are capable of supplying more than local demand. They are especially favored by water transportation to points along the coast and by railroad connections to points in the eastern half of the state and in the adjacent part of South Carolina.

Pulverized limestone is produced by the Buquo Lime Company at Hot Springs, Madison County, the Blue Ridge Lime Company at Fletcher, Henderson County, and the Clinchfield Lime Company at Asheford (Linville Falls Station), McDowell County. Part of the product enters into manufactured fertilizers, and part is applied directly to the soil. The rocks pulverized at Hot Springs and Asheford are both dolomites, or high magnesian limestones. That at Fletcher is in part high calcium and in part high magnesium, and the average product marketed is about midway between the two in composition. The State Department of Agriculture has opened a quarry and pulverizing plant in eastern Tennessee to produce high calcium rock, as the only readily accessible high calcium rock of good quality in North Carolina, except a part of that quarried at Fletcher is in Cherokee and Swain counties, where freight rates are so high that it is more economical to import limestone from Tennessee. High calcium rock of adequate purity may exist in Buncombe County northeast of Fletcher but can be located only by prospecting at considerable expense. High calcium rock has also been reported in the vicinity of Hot Springs. This was found unsuitable for burning into lime but may be satisfactory for pulverizing. By far the greater part of the limestone deposit at

Hot Springs, including that now produced for agricultural use, is the high magnesium variety. Although the State Department of Agriculture favors high calcium limestone for use on the soil, both high calcium and high magnesium limestones have been applied in various parts of the country with satisfactory results. So far as marls and high magnesium limestones are concerned, the present producers are well situated for supplying the greater part of the agricultural demand. Further discussion is given on page 167, under burned lime for agriculture.

Requirements for Other Uses

The quantity and value of limestone sold for various uses, other than the manufacture of cement and lime in 1916, 1917, and 1918, is shown in the following table.[68]

LIMESTONE PRODUCED IN THE UNITED STATES IN 1916 ,1917 AND 1918. BY USES

Use	1916		1917		1918	
	Quantity	Value	Quantity	Value	Quantity	Value
Building stone, cubic feet	11,070,230	$4,588,205	*8,481,510	4,115,366	3,698,035	$2,266,654
Approx. equivalent in short tons	930,000	----------	712,130	----------	310,640	----------
Paving blocks, number	*300,000	14,237	*438,720	7,273	c	c
Approx. equivalent in short tons	3,100	----------	1,400	----------	----------	----------
Curbing, lineal feet	*190,230	79,338	*118,940	51,972	†37,698	†37,836
Approx. equivalent in short tons	10,600	----------	6,600	----------	†3,170	----------
Flagging, square feet	*70,000	10,411	*63,130	8,327	c	c
Approx. equivalent in short tons	2,000	----------	1,700	----------	----------	----------
Rubble, short tons	*326,000	297,772	277,376	270,327	106,327	109,369
Riprap, short tons	1,600,000	1,357,457	1,007,357	854,884	1,118,109	969,276
Crushed stone, short tons	32,184,036	17,715,434	26,646,642	17,541,098	19,120,858	16,273,184
Fluxing stone, long tons	23,623,508	13,946,882	25,574,146	18,679,213	23,862,029	23,427,736
Equivalent in short tons	26,458,329	----------	28,643,044	----------	26,725,472	----------
Alkali works, short tons	2,836,557	966,262	3,124,026	1,417,898	3,437,066	2,263,821
Sugar factories, short tons	369,028	369,694	530,612	666,138	435,555	649,589
Glassworks, short tons	193,028	181,322	293,152	344,479	202,211	332,744
Paper mills	80,338	58,785	101,305	95,582	100,247	117,829
Agriculture, short tons	1,043,876	1,109,208	1,040,248	1,352,397	1,091,918	1,626,292
Lime burners, short tons	130,729	81,473	59,387	31,736	1,216,633	1,378,676
Other uses, short tons†	*1,067,380	533,119	*1,036,565	826,689		
Totals (quantities approximate, in short tons)	67,235,000	41,309,599	63,481,500	46,263,379	53,868,200	49,453,006

*Partly estimated.

†Includes stone sold as a filler for asphalt, paint, rubber, soap, and other material; stone sold for the manufacture of basic magnesium carbonate; stone sold to alcohol works and calcium carbide works dolomite sold for use in making refractory products; stone sold for chicken grit and other products

cPaving blocks and flagging included in curbing.

[68]Loughin, G. F., and Coons, A. T., Stone in 1917: Mineral Resources of the United States, 1917, part II, pp. 649 and 654, 1919. Stone in 1918: Mineral Resources of the United States, 1918; part II, pp. 1251-1285, 1920.

In addition to this great quantity the following approximate quantities were used in the manufacture of cements and lime.

Lime used in cement and lime industries in 1916, 1917, and 1918 in short tons:

	1916	1917	1918
Portland cement (including limestone and some "cement rock")	23,323,220	24,640,230	17,658,700
Natural cement	158,054	102,260	67,300
Lime	7,685,723	7,194,000	6,400,000
	31,166,997	31,963,490	24,126,000

The total quantities used for all purposes in these 3 years, about 98,400,000, 95,400,000 and 78,000,000 short tons, respectively, proves the importance of limestone in the industrial world. The three leading products, flux, crushed stone, and Portland cement, far exceed the others in quantity of limestone used. Lime is a poor fourth, stone for alkali works, fifth; agricultural stone, sixth; riprap, seventh; building stone, eighth; stone for sugar factories, ninth, and stone for glassworks, tenth. Of these products the only ones represented in North Carolina's output are flux, crushed stone, agricultural stone, and burned lime. The conditions limiting the output of the first three have already been considered. The lime industry of the state is discussed on pages 159 to 165.

As the suitability of limestone for most of the remaining uses depends upon its chemical composition, available analyses of limestones in North Carolina are given here before their qualifications for different usese are considered.

ANALYSES OF LIMESTONE IN NORTH CAROLINA

	CHEROKEE COUNTY									
	1	2	3	4	5	6	7	8	9	10
Insoluble	------	------	2.90	2.80	5.20	------	------	------	------	2.10
Silica (SiO_2)	1.20	2.93	------	------	------	0.92	1.58	0 10	------	------
Alumina (Al_2O_3)	.82	1.17	------	------	------	1.20	1.90	0.30	------	------
Ferric oxide (Fe_2O_3)	------	------	------	------	------	------	------	0.18	------	------
Ferrous oxide (FeO)	------	------	------	------	------	------	------	------	------	------
Manganese oxide (MnO)	------	------	------	------	------	------	------	------	------	------
Lime or calcium oxide (CaO)	52.90	49.83	49.10	52.30	28.62	32.80	32.40	50.52	51.56	30.14
Magnesia or magnesium oxide (MgO)	1.91	3.61	3.67	.50	19.27	15.43	19.58	4.31	3.22	20.70
Strontia or strontium oxide (SrO)	------	------	------	------	------	------	------	------	------	------
Potash or potassium oxide (K_2O)	------	------	------	------	------	------	------	------	------	------
Soda or sodium oxide (Na_2O)	------	------	------	------	------	------	------	0.13	------	------
Water below 110° (H_2O-)	------	------	------	------	------	------	------	------	------	------
Water above 110° (H_2O+)	------	------	------	------	------	------	------	0 01	------	------
Carbon dioxide (CO_2)	43.66*	43.12*	42.62*	41.64*	43.79*	42.72*	47.00*	44,28*	43.90	47.45*
Phosphorus pentoxide (P_2O_5)	------	------	------	------	------	------	------	0 06	------	------
Sulphur	------	------	------	------	------	------	------	------	------	------
Sulphur trioxide (SO_3)	------	------	------	------	------	------	------	------	------	------
Chlorine (Cl)	------	------	------	------	------	------	------	------	------	------
Totals	100.49	100.66	98.29	97.24	96.88	93.09	102.46	99.80	98.68	99.39
$CaCO_3$	94.46	88.98	87.68	93.39	51.21	58.57	57.86	------	------	53.82
$MgCO_3$	4.01	7.58	7.71	1.05	40.47	32.40	41.12	------	------	43.47
Calcite	89.68	79.95	78.50	92.14	3.03	19.99	8.91	------	------	2.07
Dolomite	8.79	16.61	16.89	2.30	88.65	70.98	90.07	------	------	95.22

*Calculated

ANALYSES OF LIMESTONE IN NORTH CAROLINA—*Continued*

	Swain County			Madison County		Mitchell County		McDowell County									
	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Insoluble	42.70				.75	.12											
Silica (SiO_2)		.95	0.01	13.20			.38	1.01	1.92	1.68	5.96	1.87	1.81	.60	1.40	2.74	1 85
Alumina (Al_2O_3)			0.50	1.82}		.11	.18	.88	1.76	.60	1.30	0.14	1.32	.70	.70	0.63	0.24
Ferric oxide (Fe_2O_3)			0.49	.42}								0.73				0.56	0.49
Ferrous oxide (FeO)				.82													
Manganese oxide (MnO)				.05													
Lime or calcium oxide (CaO)	17.62	52.33	31.00	47.35	33.31	30.67	31.29	30.93	29.69	29.97	29.13	30.68	30.59	30.29	29.23	29.52	29.68
Magnesia or magnesium oxide (MgO)	11.48	1.69	20.21	1.09	18.87	21.43	21.08	20.59	20.79	21.20	19.56	19 57	19.29	21.22	19.58	19.85	20.01
Strontia or strontium oxide (SrO)																	
Potash or potassium oxide (K_2O)			0.12	.42}			trace									0.41	0.26
Soda or sodium oxide (Na_2O)				.32}													
Water below 110° (H_2O—)				.26	.05	.13											
Water above 110° (H_2O+)				.11		.14						0.02				0.01	5 01
Carbon dioxide (CO_2)	26.47	43.20†	46.33	34.06	46.76	47.55	47.15*	46.60	45.86	46.52	44.07	45.38	46.98	47.10*	44.47*	44 77	40.07
Phosphorus pentoxide (P_2O_5)			0.06	.05								0.02				0.02	0 01
Sulphur																	
Sulphur trioxide (SO_3)				trace													
Chlorine (Cl)																	
Totals	98.27	98.17		99.97	99.74	100.15	100.08	100.01	100.02	99.97	100.02	98 41	99.99	99.91	95.38	98.51	97 62
$CaCO_3$	31.46	93.45		74.70	59.50	54.80	55.88	55.23	53.02	53.52	52.01		54.58	54.05	52.16		
$MgCO_3$	24.11	3.55		2.27	39.65	45.02	44.27	42.89	43.32	44.17	40.75		42.28	44.56	41.12		
Calcite	2.76	89.22		72.00	12.30	1.20	3.18	4.03	1.04	0.52	3.11		4.25	1.00	3.21		
Dolomite	52.81	7.78		4.97	86.85	98.62	96.97	94.09	95.30	97.17	89.65		92.61	97.61	90.07		

*Calculated.
†About 3 per cent in excess of carbonate rations; may represent water or iron carbonate.

ANALYSES OF LIMESTONE IN NORTH CAROLINA—*Continued*

	Henderson County					Jackson County	Catawba County		Lincoln County
	28	29	30	31	32	33	34	35	36
Insoluble	.13								
Silica (SiO_2)		1.40	1.70	0 47	0 33	16.45	2.60	1.28	0.45
Alumina (Al_2O_3) }		.58	.58	0.36	0.36	7.06	1.54	3.17	4.46
Ferric oxide (Fe_2O_3) }				0.16	0.38	2.80			
Ferrous oxide (FeO)									
Manganese oxide (MnO)									
Lime or calcium oxide (CaO)	53.15	53.32	53.38	51.52	32.60	39.91	34.27	33.18	35.90
Magnesia or magnesium oxide (MgO)	2.62	1.62	1.32	2.27	17.11	.25	20.09	19.07	17.63
Strontia or strontium oxide (SrO)									
Potash or potassium oxide (K_2O)				0.14	0.19				
Soda or sodium oxide (Na_2O)									
Water below 110° (H_2O-)									
Water above 110° (H_2O+)				0.05	0.01				
Carbon dioxide (CO_2)	44.32*	43.66	43.39	42.83	46.38	31.64*	†	‡	¶
Phosphorus pentioxide (P_2O_5)	(44.57)			0 05	0 01				
Sulphur									
Sulphur trioxide (SO_3)									
Chlorine (Cl)									
Totals	100.22	100.58	100.37	97.85	97.37	98.11			
$CaCO_3$	94.84	95.20	95.32			71.27			
$MgCO_3$	5.50	3.40	2.77			.52			
$FeCO_3$									
Dolomite	12.05	7.45	6.07			1.15			
Calcite	88.29	91.15	92.02			70.64			

*Calculated.

†If all lime and magnesia are calculated as carbonates the analysis totals 107.59. They are probably present in part as silicates.

‡Part of lime and magnesia probably present as silicates.

¶Calculations of all the lime and magnesia as carbonates would give a total of 106 per cent.

CHEROKEE COUNTY—No. 1. Culberson Quarry. Marble. Nitze, H. B. C., Iron ores of North Carolina, First Biennial Report of the State Geologist, 1891-92—56.

2. Kinsey Quarry. Marble. Nitze, H. B. C., Iron ores of North Carolina, First Biennial Report of the State Geologist, 1891-92—56.

3. Kinsey Quarry. Pink marble. (Pratt, J. H., N. C. Geol. Survey. Econ. Paper No. 3, pp. 22-23, 1900, Charles Baskerville, analyst.

4. Kinsey Quarry. Blue marble. (Pratt, J. H., N. C. Geol. Survey, Econ. Paper No. 3, pp. 22-23, 1900, Charles Baskerville, analyst.)

5. White marble in contact with talc. (Pratt, J. H., N. C. Geol. Survey, Econ. Paper No. 3, pp. 22-23, 1900, Charles Baskerville, analyst.)

6. Marble. Hayes place, Tomotla.

7. White marble, Hickerson's place, near Andrews (Nitze, H. B. C., Iron ores of North Carolina, Bull. 1, p. 209, 1893.)

8. Marble. Regal Quarry. W. B. Kilgore, analyst.

10. Motley Mine, one mile northeast of Tomotla. White marble in contact with talc. (Pratt, J. H., N. C. Geol. Survey, Econ. Paper No. 3, pp. 22-23, 1900, Charles Baskerville, analyst.)

SWAIN COUNTY—No. 11. Hewitts. White marble in contact with talc. (Pratt, J. H., N. C. Geol. Survey, Econ. Paper No. 3, pp. 22-23, 1900, Charles Baskerville, analyst.)

12. Hewitts. Marble. (The mining industry in North Carolina during 1901, Economic Paper, No. 6, p. 80, 1902.)

13. Hewitts. Dolomite. (State chemist.)

MADISON COUNTY—No. 14. Marble from Marshall, N. C., E. C. Sullivan, analyst. (U. S. Geol. Survey, Bull. 591, pp. 227-228, 1915.)

15. Hot Springs. G. C. Buquo Lime Co.'s quarry. Dolomitic limestone.

MITCHELL COUNTY—No. 16. Marble from Bakersville, N. C., E. C. Sullivan, analyst. (U. S. Geol. Survey, Bull. 591, pp. 227-228, 1915.) Probably the Intermont (Toecane) deposit.

17. Marble from Intermont (Toecane), furnished by the Carolina, Clinchfield and Ohio Ry.

McDOWELL COUNTY—No. 18. Dolomite from Avery tract. Furnished by Carolina, Clinchfield and Ohio Ry.

19. Dolomite from Henofer tract and adjoining lands. Furnished by Carolina, Clinchfield and Ohio Ry.

20. Dolomite from near Linville Falls Station. Furnished by Carolina, Clinchfield and Ohio Ry.

21. Dolomite from near Linville Falls Station. Furnished by Carolina, Clinchfield and Ohio Ry.

22. Dolomite from Clinchfield Lime Co., Linville Falls Station.

23. Dolomite from Pitts tract. Furnished by Carolina, Clinchfield and Ohio Ry.

24. Dolomite from Woodlawn. Diamond drill boring made by N. C. Geol. Survey, F. P. Venable, analyst.

25. Dolomite from Woodlawn. (Bull. 1, N. C. Geol. Survey, 1893, p. 233, W. B. Phillips, analyst.

26 Dolomite from Woodlawn. Analyst, N. C. Dept. of Agriculture.
27. Dolomite from Woodlawn. Analyst, N. C. Dept. of Agriculture.

HENDERSON COUNTY—No. 28. Marble from Fletcher. George Steiger, analyst. U. S. Geol. Survey, Bull. 591, pp. 227-228, CO_2 calculated to satisfy bases.

29. Limestone from Blue Ridge Lime Co., D. K. Pope, analyst. N. C. Geol. Survey, Economic Paper, No. 9, p. 76, 1905.

30. Limestone from Blue Ridge Lime Co., D. K. Pope, analyst. N. C. Geol. Survey, Economic Paper, No. 9, p. 76, 1905.

31. Limestone from Blue Ridge Lime Co. Analyst, N. C. Dept. of Agriculture.

32. Dolomite from Blue Ridge Lime Co. Analyst, N. C. Dept. of Agriculture.

JACKSON COUNTY—No. 33. Marble from Caney Fork. Partial analysis by W. T. Schaller, U. S. Geol. Survey, Bull. 591, pp. 227-228, 1915.

CATAWBA COUNTY—No. 34. Dolomite from Powell quarry. N. C. Geol. Survey, First Biennial Report, 1891-92.

35. Dolomite from the Shuford quarry. N. C. Geol. Survey, First Biennial Report, 1891-92.

LINCOLN COUNTY—No. 36. Dolomite from the Keener quarry. N. C. Geol. Survey, First Biennial Report, 1891-92.

Most of these analyses were incomplete, and the percentage of carbon dioxide was calculated. Where silica, alumina, and iron are very low, the calculated percentage is essentially accurate, and where it does not bring the total within 0.25 of 100, some error has evidently been made in the analyses. Where alumina, iron and especially silica amount to considerably more than 1 per cent, a part of the lime and magnesia were probably combined with them to form such minerals as feldspar, tremolite, and epidote, and the calculated percentage of carbon dioxide is correspondingly too high. This is evidently the case in analyses Nos. 7, 14, and would be in Nos. 37, 38, and 38, in which calculated carbon dioxide would bring the totals to as much as 106 or 107 per cent. In analysis No. 17, where carbon dioxide has been definitely determined, it is insufficient to balance both lime and magnesia. If all the magnesia is regarded as carbonate, only 41.83 of the 47.35 per cent of lime can be present as carbonate, the balance entering into epidote and other silicates which are known to be present. Where, in spite of the rather high percentage of impurities and the calculated carbon dioxide, the total is considerably below 100, the difference may be due in part to failure to determine other constituents, notably alkalies, but is more probably due to inferior analytical work.

The incompleteness of the analyses is also shown by the general failure to separate alumina and iron oxides, or to determine the constituents of "insoluble." Without accurate determination of these constituents it is impossible to state whether a limestone can be recommended for certain uses.

PORTLAND CEMENT

Portland cement is made by burning a definite mixture of finely ground limestone and shale, or other rock containing the requisite quantities of silica, alumina, and iron oxides to fusion, and finely grinding the resulting clinker. The raw mixture contains about 75 per cent calcium carbonate and 25 per cent of silica, alumina, and iron. As the limestone is finely ground its original form is of little consequence, and may be ordinary limestone, marble, chalk, or marl. Furthermore, as a certain quantity of silica, alumina, and iron is to be mixed with it the presence of these impurities in the limestone is not objectionable. Some limestones contain approximately enough of them to yield a cement without admixture of shale, and are called cement rock. Large quantities of "natural cement" were formerly made from cement rock, but the more carefully prepared Portland cement has almost entirely replaced it in the building industry. Limestone for Portland cement, however, must not contain more than 7 per cent of magnesia, as magnesia tends to hydrate, or combine chemically with water, after the cement is in use, causing it to swell and disintegrate. The alkalies were formerly considered undesirable, if in any considerable quantity, but may be volatilized during burning and a large part of the potash present recovered as a by-product.

Few of the analyses on page 149 are sufficiently complete to show the potash content, but magnesia and silica, alumina, and iron together or separate are shown in all. "Insoluble" shown in some of the analyses consists principally of silica and alumina with some iron. In most of the analyses the magnesia is much higher than the maximum allowance for Portland cement.

By far the most promising deposits for manufacture of cement are those along the Murphy Branch in Cherokee and Swain counties. From Murphy northeast to Marble Station there is high calcium limestone (marble), accompanied by beds of high magnesium limestone; but it lies in depressions so that quarry operations necessarily involve pumping. As the formation is largely concealed beneath soil, it is impossible to predict where a sufficient quantity of high calcium rock free from high magnesium rock can be found. The marble quarry at Regal gives a general idea of the relation between topographic and quarrying conditions and shows the largest exposure of high calcium rock in the state. A gravity water supply can be obtained from creek tributary to Valley River. From Marble east to Andrews the broad valley along the railroad is underlain by marble. The only available analysis ((No. 12) shows a high magnesium content, but it is possible that prospecting with a drill may disclose a sufficient quantity of high calcium rock. The marble area along the Murphy Branch from Nantahala to Hewitts, Swain County, contains both high calcium and high magnesium rock. Quarries here can be made self-draining and plenty of water for use at the plant may be obtained by gravity.

Although there is no true shale near these marble deposits, they are bordered by the Valleytown formation, which includes large quantities of slate and mica schist or metamorphic shale, parts of which may not only prove to be of suitable composition for Portland cement manufacture but to contain enough potash to yield a profitable by-product.

By-product potash from Portland cement plants is the most promising source of domestic potash after normal conditions of international trade are re-established and is especially worthy of consideration in this case as the southeastern states are by far the largest consumers of potash in the country.

There is a general complaint that high freight rates have retarded developments of limestone and marble resources along Murphy Branch, and the distance from adequate markets and sources of fuel supply is also unfavorable to the establishment of a Portland cement plant in this area.

High calcium limestone is reported from the vicinity of Hot Springs, Madison County, but all specimens collected during recent study prove to be dolomitic, and available analyses show high magnesium content. The high calcium rock is said to have crumbled and choked the kiln during attempts to burn it into lime. This behavior may well have been due to presence of unsuspected dolomite (Mg.-Ca. Carbonate), which may decompose with explosive violence if heated too rapidly. High calcium and high magnesium rocks frequently occur in thin alternate beds, and the sample taken from a high calcium bed may have failed to show the average magnesium content.

The red Watauga shale is abundant on the north side of the main limestone body, both east and west of the river. Other rocks that may be suitable for mixing with the limestone are the Hiwassee slate, which forms the steep slope along the railroad from Putnam westward for more than a mile; the Nichols slate, which crosses the river about 1¼ miles southeast of Hot Springs and covers a considerable area northwest of Hot Springs near Paint Rock; and the Murray Slate, which forms a narrow east-west band several miles long extending along the south edge of Hot Springs. The gneiss in the vicinity of Marshall may also deserve consideration because of the potash content.

Near Fletcher, Henderson County, high calcium and high magnesium rocks (analyses Nos. 28 to 32, page 151) are exposed in the Blue Ridge Lime Company's quarry, which is connected by spur track 2 miles long with the Southern Railroad. The limestone formation here is a lens about 1 mile long, but should be carefully prospected before a new quarry is opened. The limestone underlies a flat valley and quarry operations involve pumping. There is no gravity water supply readily available. The adjoining rock, called the Brevard schist, is a mica schist which may prove suitable for mixing with the limestone and for yielding by-product potash.

High calcium rock may also form parts of the other limestone lenses northeast and southwest of Fletcher, but its presence can be determined only by considerable careful prospecting.

The only other prospects worthy of any consideration are in the vicinity of Kings Mountain (city). This limestone also is so thoroughly concealed that much prospecting is necessary to determine its character; but at one or two places, notably at the steep source of a south dry branch of Abernathy Creek, one-half mile east of the railroad and 1½ miles northeast of Kings Mountain, the topography is favorable for quarrying. For the most part the formation lies along creek bottoms and the cost of pumping would preclude any extensive quarry development. The limestone where exposed contains many thin partings of micaceous shale, which vary in quantity to such extent that an unusually careful check should be kept on the chemical composition of the rock produced. No analyses of this limestone are available.

Marls are abundant in Coastal Plain region, but their analyses, according to E. C. Eckel[69] show them to be unsuitable as quarried for the manufacture of Portland cement.

ALKALI MANUFACTURE[70]

In the manufacture of soda ash both lime and carbon dioxide are used, and manufacturers therefore obtain limestone and burn it themselves rather than purchase the two products separately. High magnesium limestone is said to be unsuited for this industry, although the objectionable properties of magnesium are not stated. Caustic soda is made by dissolving soda ash in water and adding lime. Magnesia is inert and its presence lowers the percentage of active lime. Impurities tend to contaminate the finished product. High calcium limestone as free as possible from impurities is therefore required, and only a few

[69]Eckel, E. C., Cement materials and industry of the United States: U. S. Geol. Survey, Bull. No. 522, pp. 298-299, 1913.

[70]For a more general discussion of and references to the manufacture here cited, see Emley, W. E., The source, manufacture, and use of lime: Mineral Resources of the U. S., Calendar Year 1913, pp. 1585-1593, U. S. Geol. Survey, 1914.

of the analyses quoted, notably Nos. 1, 15, and 31-34, represent rock of satisfactory quality.

SUGAR MANUFACTURE

Both lime and carbon dioxide are also used in the manufacture of sugar, and many manufacturers therefore buy the limestone and burn it, although a considerable number buy burned lime. Magnesia and silica are both troublesome and each should constitute less than 2 or 3 per cent of the rock, a requirement which limits the state's resources to the high calcium deposits represented by analyses Nos. 1, 15, and 31-34.

GLASS MANUFACTURE

Ground limestone is generally used in the manufacture of glass, but quicklime and hydrated lime are sometimes used. Magnesia renders the glass more difficult to melt, but is a valuable constituent in certain glasses. For all but cheap green glass the content of iron oxide must be less than 0.3 per cent and for optical glass less than 0.05 per cent.[71] Only a few of the analyses on page 149 show iron oxides separately. Qualitative tests, however, have proved that the high magnesium limestones of the state are prevailingly higher in iron than the high calcium stones. Microscopic and chemical examination shows the marble in the Regal quarry to have a remarkably low content of iron, even where the per cent of magnesia may be considerable. The high calcium stone in the Blue Ridge Lime Company's quarry at Fletcher is also probably low enough in iron, and this small quantity could be still further reduced if it were practical to select stone free from black streaks. On the other hand, a specimen of high calcium, or at least low magnesium stone from the south quarry at Hewitts has an unusually high content of iron. Information thus far available would restrict the resources of limestone for the manufacture of high-grade glass to the present quarries at Regal and Fletcher.

PAPER MANUFACTURE

Both high calcium and high magnesium lime and high calcium limestone are used in different processes of paper manufacture, but of five processes, soda, sulphite, sulphate, rag, and strawboard, all but the sulphite process, call for high calcium lime, in which calcium oxide is the only useful ingredient. The sulphite process, if "milk of lime" is used, calls for a high magnesium lime carefully burned, containing at least

[71]A recent article by F. Gelstharp (The use of lime in the glass industry: Rock products, Aug. 30, 1919, p. 80) quotes a series of analyses of limestone that have been found satisfactory for glass making, in which iron (ferric) oxide ranges from 0.02 to 0.26 per cent, and magnesium carbonate from 0.50 to 1.55 per cent (in one exceptional analysis 10.25 per cent). Silica and clay ("insoluble") range from 0.08 to 1.00 per cent, and alumina 0.04 to 0.12 per cent. The distinction of alumina from clay (aluminum silicate) is not explained. He states that the limits of impurities in a fairly good limestone for use in the manufacture of ordinary kinds of glass to be, clay and silica 1.5 per cent, ferric oxide 0.15 per cent, alumina 0.10 per cent.

37 per cent magnesium oxide (about 19.4 per cent in the unburned stone), and not more than 3 per cent of silica, alumina, and iron oxides together; if raw limestone is used it calls for a high calcium limestone containing at least 94 per cent calcium carbonate, not more than 1.5 per cent of combined silica, alumina, and iron oxide, and not more than 5 per cent of magnesia.[72] Of the analyses quoted, only Nos. 15 and 31 meet the requirement of raw limestone for the sulphite process. These are also the best for the other processes, although lime from stone represented by analyses Nos. 1-4 and 32-34 may also be used if obtainable at lower cost than purer limestone. Of the high magnesium limestones Nos. 10, 19, 20, 21, 23, 27, 28, and perhaps 18, should yield lime suitable for the sulphite (milk of lime) process. High magnesium lime was furnished for this process by one producer until a few years ago, when the consumer changed to a different process.

DEAD-BURNED DOLOMITE

Since the war has cut off the supply of Austrian magnesite, formerly used for flooring and lining basic open-hearth steel furnaces and copper furnaces, there has been a rapidly growing demand for dead-burned or sintered dolomite. The purer and perhaps some of the less pure dolomites, or high magnesium limestones in North Carolina, should prove suitable for this use. A small quantity of North Carolina dolomite was shipped for use as a flux in open-hearth steel furnaces in 1918, but the cost of producing the dead-burned product, which requires admixture with a small percentage of ground clay or slag and reburning at a high temperature, would discourage this enterprise unless operation on a large scale could be assured. The larger metallurgical centers are supplied from dolomite deposits much nearer than those in North Carolina.

BASIC MAGNESIUM CARBONATE

"Basic magnesium carbonate," or magnesium alba, is a mixture of the carbonate and hydrate of magnesium made by the removal of calcium carbonate from dolomite. The resulting product is particularly valuable for heat insulation, and is mixed with 15 per cent asbestos to make pipe and furnace coverings and other forms of insulators. As the principal demand for this product is in the leading manufacturing centers, most of which are included in the northeastern part of the country, the dolomite deposits best situated for supplying raw material are some of those in Pennsylvania and Ohio. There is very little prospect at present of a demand for North Carolina dolomite for this purpose.

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[72]Specifications for the sulphite process from a letter to the writer by C. F. Rhodes, International Paper Co.

BUILDING STONE

With the exception of the marble of the state, whose commercial importance has already been considered, there is no limestone or dolomite in western North Carolina that is attractive as a building stone and that can therefore attain more than a local market for roughly trimmed stone. The structure of the stones is unfavorable for the production of curbing, flagging, or paving. Even for local use the cost of opening a quarry to supply the necessarily small demand would be too great to encourage the attempt. Riprap and rubble are supplied from waste rock or from quarries opened near some large engineering project. At most places in western North Carolina other kinds of stone are more available for these uses than limestone. The local use of shell rock for building in the eastern part of the state where no other suitable rocks are found is described on page 132.

MINOR USES

There is a great variety of minor uses for limestone, for example, chicken grit, filler for asphalt, paint, and other materials, and filler stone, but none of these alone is sufficient to give much encouragement to the opening of new quarries in the state.

LIME

Production in North Carolina

The production of burned lime in North Carolina since 1901 is shown in the following table:

LIME SOLD IN NORTH CAROLINA, 1901-1918

	Quantity	*Value*	*Average price per ton*	*Number of Plants in Operation*
1901	....	$ 3,598	...	..
1902	....	2,090	...	..
1903	....	600	...	..
1904	920	4,800	$5.22	..
1905	1,792	7,980	4.45	..
1906	5,896	41,468	7.03	5
1907	5,000	24,010	4.80	4
1908	5,132	24,750	4.82	5
1909	9,881	44,148	4.47	7
1910	9,952	40,455	4.07	7
1911	7,809	33,543	4.30	6
1912	6,693	30,559	4.57	4
1913	9,815	47,838	4.87	4
1914	8,098	36,356	4.49	3
1915	a	a	4.92	2
1916	a	a	5.50	1
1917	a	a	7.41	2
1918	a	a		1

a Less than three producers. Figures withheld to avoid disclosure of confidential information.

The production of lime until 1905 served to supply small local demands. In 1904 the Blue Ridge Lime Company opened a quarry and erected two kilns near Fletcher, Henderson County, and in 1905 added two more kilns. The plant was connected with the Southern Railroad by a tramway, and later by a broad gauge railroad, 2 miles long, and a market of considerable extent established. In the few following years, presumably because of increased costs of manufacture, production for local consumption gradually ceased, and since 1915 the Blue Ridge Lime Company has been the only continuous producer. There was formerly intermittent production of lime reported from Buncombe, Transylvania, and Yadkin counties in the western part of the state, and from New Hanover, Jones and Pender counties in the eastern part. Small production for local use, of which there is no definite record, was formerly made in other counties whose limestone deposits are described in this report. Production for local demand was a feature of the lime industry before the development of railroad facilities, improved methods of manufacture and increased cost of operations rendered production on a small scale by crude methods impractical.

Some increase in production of lime is to be expected when the plans of the Clinchfield Lime Company to erect kilns and a hydrating plant at Asheford (Linville Falls Station) are carried out. The Carolina Lime Company has been recently organized to produce lime in the vicinity of Woodlawn, McDowell County. Both of these properties are near enough to the Carolina, Clinchfield and Ohio Railroad to have ready access to all the principal markets of North Carolina and South Carolina. With the establishment of these two companies the best quarry sites in North Carolina have been taken up, and there is little prospect of further growth of the limestone and lime industries of the state; for any marked increase in demand could be more economically met by increase in the output of existing plants and by imports from adjacent states than by the development of deposits within the state but poorly situated for quarrying or transportation.

Production and Consumption in the Southeastern States

North Carolina's position in the burned lime industry during 1916 and 1917, compared with other southeastern states, is shown in the accompanying table. During each of these years North Carolina ranked 28th among the lime producing states of the country, and 6th among the 7 producing states in the southeast. Virginia, which ranks third among the producing states of the country, consumes a large quantity of lime and also supplies markets in Maryland, Pennsylvania, and the District of Columbia, and other northern states, but the largest consumer of Virginia lime is North Carolina. West Virginia, which ranks fourth, is a comparatively small consumer, but has its principal lime plants near its northern border, conveniently situated for supplying markets in several of the northern states. Tennessee, which ranked 12th in 1916 and 13th in 1917, consumes only from one-fourth to one-third as much lime as the lime produced, and ships most of the remainder to other southern states, particularly North Carolina. The same general statement applies to Alabama, which ranks 16th, among the lime producing states. Florida, which ranked 26th in 1916 and 24th in 1917, consumes almost its entire output and about two-thirds as much again, but its per capita consumption, like that of most of the southeastern and southwestern states, is low.

LIME CONSUMED IN SOUTHEASTERN STATES IN 1916 AND 1917

	Lime				Population	Consumption of Lime per Capita (Short Tons)
	Produced (Short Tons)	Consumed (Short Tons)	Shipped out of State	Shipped into State		
1916						
Alabama	67,524	22,977	48,452	3,905	2,332,608	0.01
Florida	8,666	13,972	144	5,450	893,493	.015
Georgia		33,291		33,291	2,856,065	.01
Kentucky	1,236	21,267		20,031	2,379,639	.01
Mississippi		12,441		12,441	1,951,674	.006
North Carolina		77,741		72,189	2,402,738	.03
South Carolina		12,708		12,708	1,625,475	.01
Tennessee	109,533	31,803	79,422	1,692	2,288,004	.01
Virginia	326,812	236,918	124,945	35,051	2,192,019	.11
West Virginia	277,721	46,718	263,192	32,189	1,386,038	.03
1917						
Alabama	66,744	22,921	47,426	3,603	2,363,939	.01
Florida	9,914	16,231	264	6,581	916,185	.017
Georgia		39,957		39,957	2,895,841	.01
Kentucky	723	19,860		19,137	2,394,093	.008
Mississippi		11,368		11,368	1,976,570	.006
North Carolina		60,569		55,557	2,434,381	.02
South Carolina		14,090		14,090	1,643,205	.01
Tennessee	101,836	23,761	80,769	2,694	2,304,629	.01
Virginia	307,195	226,633	115,729	35,167	2,213,025	.10
West Virginia	245,569	36,399	230,415	21,245	1,412,602	.025

The per capita consumption of lime for the country was .04 ton in 1916 and .037 in 1917. With the exception of Virginia, all southern states are below the average. Virginia, Maryland, Pennsylvania, and Delaware include some of the most thickly settled industrial districts in the country and are correspondingly far above the average. Only

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14 states and the District of Columbia equaled or exceeded the average in 1916 and 1917. North Carolina's consumption of lime is not far below the average per capita and is considerably greater than that of any other southeastern state.

In normal times from 40 to 45 per cent of the lime produced is used for building, and approximately equal quantity goes to chemical works and manufacturing plants which require lime in their process, and the remainder is used mostly in agriculture. North Carolina, therefore, evidently surpasses most of the neighboring states in the number of buildings of superior quality erected annually, but its principal cities are small compared with those of states whose consumption of lime equals or exceeds the average per capita. No great increase in the consumption of building lime is, therefore, to be expected, although substantial gains may result from the use of hydrated lime in concrete construction work, as recommended by many construction engineers.

The industrial growth of North Carolina and of the south as a whole is promising as regards increased consumption of chemical lime. Statistics are not available to show any growth in the state's use of chemical lime. Of the lime produced within the state some has been used for tanning and for the cooking of pulp for the manufacture of paper, but data regarding these uses are too few to be significant. Most of the chemical lime used has been brought in from other states.

Data regarding burned lime, or quicklime, for agriculture are also too meagre to show definitely any changes in demand for it. Although some authorities have claimed that the caustic property of quicklime is injurious to soil, recent demonstrations have disproved this claim, and preference for quicklime, hydrated lime, or pulverized limestone is based mainly on the readily available content of lime and magnesia and differences in cost. Producers of both quicklime and pulverized limestone have found that farmers located close by railroads tend to favor the relatively low priced limestone whose content of lime and magnesia ranges from below 50 to 55 per cent, whereas those who must haul their lime a considerable distance from the railroad to the farm prefer the relatively high priced quicklime whose content of lime and magnesia ranges from 95 to 98 per cent. For certain purposes, whose discussion is beyond the scope of this report, one form of lime may be preferable to the others, but in general the choice depends upon the ultimate cost of applying a certain quantity of available lime and magnesia to the soil.

Relation of North Carolina's Resources to Requirements

In view of North Carolina's considerable consumption of lime compared with its small production, what are the prospects of supplying more of the state's requirements from within its own boundaries? These depend upon the quality of lime required, the quality that is and can be produced and the cost of getting it to market. The one lime-producing company that was active in 1918 has both high calcium and high magnesium rock in its quarry. It can produce high calcium lime, but its high magnesium stone tends to choke the kiln during burning if used alone. The two are or can be burned together, producing a lime of intermediate composition. The other two companies mentioned on page 160 can be expected to produce only high magnesium lime. None of these three companies are poorly situated as regards transportation. The company which has produced lime at Hewitts, Swain County, has high magnesium rock which burns well, and high calcium rock which, though of good chemical composition, burns to an unsatisfactory color. It may, however, be handicapped by high freights which may place it at a disadvantage compared with producers of the same qualities of lime, not only within North Carolina but in eastern Tennessee as well. In the undeveloped deposits, or those worked intermittently on a small scale, both high calcium and high magnesium rocks occur abundantly in the Cherokee-Swain County area, but are handicapped by high freight charges; other high calcium rock may be found in the Fletcher-Boylston-Brevard group of deposits but most of the stone worked or tested is magnesian, and is a considerable distance from a railroad. Only high magnesium stone has been proved to exist in other deposits whose location entitles them to commercial consideration. The marl deposits in the eastern part of the state are nearly all high calcium, but attempts to produce burned lime from them have been unsuccessful.

BUILDING LIME

Building lime is made from both high calcium, high magnesium and intermediate rock, but the different varieties of stone do not behave identically during or after burning. High magnesium stone decomposes at a lower temperature than high calcium stone, and if burned by one accustomed to high calcium stone is likely to become somewhat sintered or overburned. Overburned particles of lime tend to slake incompletely during the mixing of mortar or plaster, and later to complete their slaking in the wall causing the plaster to "pop." Any kind of lime will "pop" if incompletely slaked, but the mistreatment of high magnesium lime by one unaccustomed to high calcium lime may result in an unusually large amount—enough to condemn the lime. Dolomite, the chief mineral constituent of high magnesium limestone, may decompose with explosive violence if heated too rapidly,[73] and the resulting fine material will then choke the draft in the kiln—another disadvantage that results if the properties of the stone are not appreciated. There are other causes of draft-choking, for example, the presence of a small percentage of free silica which unites with lime to form calcium disilicate, whose formation is accompanied by sudden expansion which reduces the lumps of stone to powder. The choking of the draft by high calcium stone may be due to this cause or to the unsuspected presence of some dolomite. Both high calcium and high magnesium rocks may contain a considerable quantity of occluded hydrogen sulphide or other gasses whose expansion during too rapid heating may cause disintegration and draft-choking.

Properly burned high magnesium lime slakes more slowly and with less evolution of heat than high calcium lime, and this difference may also result in improper treatment of one variety of lime by one accustomed to another kind. The magnesia or magnesium oxide in burned lime does not slake when water is added under ordinary conditions, that is at atmospheric pressure, as it constitutes about half the volume of high magnesium lime, or, in other words, as it dilutes the active constituent of lime by about 50 per cent only a proportionate quantity of water is required for slaking and only about half the heat is evolved during slaking that would be evolved by an equal quantity of high calcium lime; but it takes water longer to reach all the active particles. The amount of shrinkage during the settling of the lime and the amount of sand that should be added to make a good mortar will also vary according to the quantities of active calcium oxide and inactive magnesium oxide in the lime. Some slaked limes, particularly certain high magnesium limes, have a much higher degree of plasticity or spreading quality than others, and are held in such high favor that they have been shipped to markets hundreds and even thousands of miles away. The cause of this quality has never been satisfactorily determined. A few limes possess it to a marked degree, whereas others of practically identical composition are deficient in it.

This brief discussion of the principal differences between the two kinds of lime will readily explain some of the prejudices held against either kind for certain uses. It is said that in eastern Pennsylvania, where large quantities of high magnesium lime are produced, high calcium lime is held in disfavor by builders, whereas the reverse is true in Virginia, where there is a large production of high calcium lime.

[73]Hildebrand, W. F., Chemical analyses of silicate and carbonate rocks. U. S. Geol. Survey Bull. 700, p. 212, 1919.

In North Carolina the one important manufacturer of building lime produces a high calcium product, or at least one with only a low content of magnesia. The preferences of builders is not known to the writer, but the fact that so much lime is shipped in from the high calcium districts of Virginia, Tennessee, and Alabama, suggests a preference for high calcium lime. Some of the largest deposits of high magnesium limestone in the state appear to be well suited for burning into lime and to be advantageously situated as regards transportation to the principal cities of the state; but those of high calcium stone, other than the one now worked, are less favorably situated.

Increase in the production of building lime in North Carolina depends, therefore, on the demonstration that a good quality of high magnesium lime can be produced on a commercial scale and on the proper treatment of the lime by the builder. Difficulties attending the slaking or hydrating of the lime may be overcome by the installation of a hydrating plant by the producer, which will enable him to furnish properly hydrated lime to the builder with explicit instructions regarding its sand-carrying capacity and the quantity of water to be used in mixing.

CHEMICAL LIME

The use of lime in chemical industries has greatly increased in recent years, and at the present rate of increase will soon become the principal use. There are considerably more than one hundred uses of lime in manufacturing industries, including the manufacture of sundry chemicals, and of such products as paper, sugar, and leather. Almost none of these chemicals and other products contain lime, but is necessary to bring about certain chemical reactions in the process of manufacture. The composition of the lime, as of limestone, is more important in the chemical industries than in the building industry, as the impurities in the lime may produce undesired reactions, or, if inert, may lower the efficiency of the lime and increase the cost of operation.

The most prominent impurities in lime as shown by the analyses of limestone on page 149 are silica, alumina and iron oxides. Other impurities may be present in minute quantities but are seldom determined in analyses of burned lime. Magnesia may be regarded as an essential constituent or an impurity according to the particular chemical process under consideration. Some limes have been shipped across several important lime-producing states because of their unusually low content of silica and magnesia; others because of their high content of magnesia, but almost total freedom from iron. In contrast to these both high calcium and high magnesium limes are equally suited for some uses, and it may make little or no practical difference whether quicklime, hydrated lime, or ground limestone is used. A great deal of investigation remains to be carried on before the essential properties of limes for different chemical uses are thoroughly understood and appreciated. The following statements will serve, however, to outline the principal requirements of lime for some of the more important industries, named in order according to the quantity of lime used annually by them in the United States.[74]

Paper Manufacture.—This use has already been considered under limestone.

Tanning.—In the leather industry limewater is used for loosening the hair from the hide, and high calcium lime is usually required. Magnesia, silica, alumina are injurious because they make the lime more difficult to slake, and iron because it may cause stains in the leather. One special process, however, calls for lime with very high magnesium but with less than 0.10 per cent of iron.

Sugar Manufacture.—This use also has been considered under limestone.

Glass Manufacture.—This use also has been considered under limestone used in the manufacture of glass. Calcium oxide is always essential. Magnesia may be desirable or undesirable according to the kind of glass to be made. Iron imparts a green color to glass. For white glass oxides of iron must be less than 0.3 per cent, and for optical glass less than 0.05 per cent of the unburned stone.

Calcium cyanamid.—Calcium cyanamid is prepared by heating a mixture of lime and coke in an electric arc furnace and treating the fused mass with nitrogen, which is obtained from the fractional distillation of liquid air. High calcium quicklime is required. Impurities are undesirable on account of the expense required to heat them, and limestone containing 97 per cent calcium carbonate was specified as the raw material for the Government plants. The cyanamid plants authorized by the Federal Government were designed to consume lime equivalent to 500 tons of limestone a day. This large demand would place a premium on suitable stone within a short distance of the plant.

Illuminating gas.—High calcium lime is essential for the purifying of illuminating gas derived from coal. Calcium oxide is the only useful constituent, although magnesia and impurities are not harmful.

[74] A more extended outline of the requirements for different chemical uses of lime is given by Emley, W. E., in "The source, manufacture, and use of lime": Mineral Resources of the United States, Calendar year 1913—Part II, pp. 1581-1593, U. S. Geological Survey, 1914.

Oil, fat, and soap manufacture.—In these industries also calcium oxide is the only useful constituent of lime, although magnesia and impurities are not harmful.

Other industries.—For most other industries using lime, calcium oxide is necessary or desirable, although magnesium lime may be equally suitable for some. Those which require high magnesium lime are few in comparison. The preponderance of high magnesium limestone in North Carolina, therefore, is not favorable for the attraction of many of the chemical industries. The most favorable districts are those along the Murphy Branch of the Southern Railroad, but these, as already stated, have been handicapped by high freight rates, and it has not been demonstrated whether they are free enough from interbedded dolomite to supply large requirements like those of the Government cyanamid plants. The only chemical uses that have been reported from North Carolina lime are paper manufacture (sulphite process) which calls for high magnesium lime, and tanning, which calls for high calcium lime.

AGRICULTURAL LIME

The remarks on page 146 regarding agricultural limestone apply as a whole to agricultural lime, whether in the form of quicklime or hydrated lime. Quicklime is especially adapted for certain uses, such as deflocculation of clay in heavy, sticky soils, and quick reaction with acids and other ingredients of the soil. High calcium lime would have a greater deflocculating effect than high magnesium lime. Hydrated lime is especially desirable wherever the caustic property of quicklime is not wanted, and where more rapid reaction is wanted than can be obtained from pulverized limestone. The effectiveness of unburned stone varies with the fineness to which it is ground. Pulverized stone, 100 per cent of which can pass through a 200-mesh screen, reacts with comparative rapidity, whereas ground stone, which can only pass a 10-mesh screen, is relatively ineffective for rapid reaction. Unburned stone, moreover, contains only about half as much available lime and magnesia as the corresponding burned lime. The presence or absence of magnesia is apparently of little consequence as a rule, although magnesia may be especially desirable or undesirable for certain crops. The main factor in deciding among these three forms of lime, therefore, as stated on page 162, is the ultimate cost per unit of efficiency to the consumer.

Of the limes and limestone in North Carolina marketed for agricultural use, those produced for several years by private companies have had a moderate to high content of magnesia, whereas the limestone (from east Tennessee) and marl produced by the State Department of Agriculture have been calcium products. The prospects of increasing the total output of agricultural lime and limestone in the state are good, but are limited by the territory which can be more cheaply supplied from these sources than from sources outside of the state.

Future of the Marble, Limestone, and Lime Industries in North Carolina

The foregoing discussion forces the conclusion that scope of the limestone industries, including marble and lime, is not likely to increase greatly. Although one marble company has maintained a considerable output, particularly of monumental stone, several other attempts to open quarries have been unsuccessful, largely because of defects in the stone, and in part probably because of insufficient capital, and adequate nearby markets, where the stone could have been introduced at minimum cost. A few prospects, however, afford hope that good quarries can be developed from them if funds are available for the necessarily expensive preliminary work of removing shattered surface rock and reaching sound stone below.

The demand for crushed limestone is likely to increase as the "good roads" movement grows in territory that can be readily supplied with North Carolina's limestone, and there is every reason to expect the normal increase in production of pulverized limestone to continue. The fact that the production of flux failed to increase during the period of intensive metallurgical activity gives little hope for marked increase in the future. Marked growth in the production of burned lime depends largely upon the successful introduction and handling of high magnesium lime for building purposes, and establishment of paper mills using the sulphite (milk of lime) process of preparing wood pulp. The location of the largest high calcium deposits is not very favorable for the establishment of Portland cement plants or of chemical manufacturers calling for high calcium lime, except perhaps paper mills. Markets and the sources of other essential raw materials are too distant to attract the other more important industries. Waterpower is plentiful in western North Carolina, however, and its future development may offset the present disadvantages. Whenever this change takes place the high calcium limestones particularly will increase in commercial importance.

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PUBLICATIONS

OF THE

NORTH CAROLINA GEOLOGICAL AND ECONOMIC SURVEY

BULLETINS

1. Iron Ores of North Carolina, by Henry B. C. Nitze, 1893. 8°, 239 pp., 20 pl., and map. *Out of print.*

2. Building and Ornamental Stones in North Carolina, by T. L. Watson and F. B. Laney in collaboration with George P. Merrill, 1906. 8°, 283 pp., 32 pl., 2 fig. *Postage 25 cents. Cloth-bound copy 50 cents extra.*

3. Gold Deposits in North Carolina, by Henry B. C. Nitze and George B. Hanna, 1896. 8°, 196 pp., 14 pl., and map. *Out of print.*

4. Road Material and Road Construction in North Carolina, by J. A. Holmes and William Cain, 1893. 8°, 88 pp. *Out of print.*

5. The Forests, Forest Lands, and Forest Products of Eastern North Carolina, by W. W. Ashe, 1894. 8°, 128 pp., 5 pl. *Out of print.*

6. The Timber Trees of North Carolina, by Gifford Pinchot and W. W. Ashe, 1897. 8°, 227 pp., 22 pl. *Out of print.*

7. Forest Fires: Their Destructive Work, Causes and Prevention, by W. W. Ashe, 1895. 8°, 66 pp., 1 pl. *Out of print.*

8. Water powers in North Carolina, by George F. Swain, Joseph A. Holmes, and E. W. Myers, 1899. 8°, 362 pp., 16 pl. *Out of print.*

9. Monazite and Monazite Deposits in North Carolina, by Henry B. C. Nitze, 1895. 8°, 47 pp., 5 pl. *Out of print.*

10. Gold Mining in North Carolina and other Appalachian States, by Henry B. C. Nitze and A. J. Wilkins, 1897. 8°, 164 pp., 10 pl. *Out of print.*

11. Corundum and the Basic Magnesian Rocks of Western North Carolina, by J. Volney Lewis, 1895. 8°, 107 pp., 6 pl. *Out of print.*

12. History of the Gems Found in North Carolina, by George Frederick Kunz, 1907. 8°, 60 pp., 15 pl. *Out of Print.*

13. Clay Deposits and Clay Industries in North Carolina, by Heinrich Ries, 1897. 8°, 157 pp., 12 pl. *Out of print.*

14. The Cultivation of the Diamond-back Terrapin, by R. E. Coker, 1906. 8°, 67 pp., 23 pl., 2 figs. *Out of print.*

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18. Bibliography of North Carolina Geology, Mineralogy, and Geography, with a list of Maps, by Francis Baker Laney and Katherine Hill Wood, 1909. 8°, 428 pp. *Postage 25 cents. Cloth-bound copy, $1.00.*

19. The Tin Deposits of the Carolinas, by Joseph Hyde Pratt and Douglas B. Sterrett, 1905. 8°, 64 pp., 8 figs. *Postage 4 cents.*

20. Water powers of North Carolina: An Appendix to Bulletin 8, 1910. 8°, 383 pp. *Postage 25 cents.*

21. The Gold Hill Mining District of North Carolina, by Francis Baker Laney, 1910. 8°, 137 pp., 23 pl., 5 figs. *Postage 15 cents. Cloth copies 75 cents.*

22. A Report on the Cid Mining District, Davidson County, N. C., by J. E. Pogue, Jr., 1911. 8°, 144 pp., 22 pl., 5 figs. *Postage 15 cents. Cloth copies 75 cents.*

23. Forest Conditions in Western North Carolina, by J. S. Holmes, 1911. 8°, 116 pp., 8 pl. *Postage 15 cents.*

24. Loblolly or North Carolina Pine, by W. W. Ashe, Forest Inspector, U. S. Forest Service (and former Forester of the North Carolina Geological and Economic Survey). Prepared in Coöperation with the Forest Service, U. S. Department of Agriculture, 1914. 8°, 176 pp., 27 pl., 5 figs. *Postage 15 cents. Cloth copies 75 cents.*

25. Zircon, Monazite, and Other Minerals used in the Production of Chemical Compounds Employed in the manufacture of Lighting Apparatus, by Joseph Hyde Pratt, Ph.D., 1916. 8°, 120 pp., 3 pl. *Postage 15 cents. Cloth copies 75 cents.*

26. A Report on the Virgilina Copper District of North Carolina and Virginia, by F. B. Laney, Ph.D., 1917. 8°, 176 pp., 20 pl., 16 figs.

27. The Altitudes of North Carolina, 1917. 8°, 124 pp. *Postage 20 cents.*

28. Limestones and Marls of North Carolina, by G. F. Loughlin, E. W. Berry, and J. A. Cushman, 1920. 8°, 211 pp. *Postage 15 cents.*

ECONOMIC PAPERS

1. The Maple Sugar Industry in Western North Carolina, by W. W. Ashe, 1897. 8°, 34 pp. *Postage 2 cents.*

2. Recent Road Legislation in North Carolina, by J. A. Holmes. *Out of print.*

3. Talc and Pyrophyllite Deposits in North Carolina, by Joseph Hyde Pratt, 1900. 8°, 29 pp., 2 maps. *Postage 2 cents.*

4. The Mining Industry in North Carolina During 1900, by Joseph Hyde Pratt, 1901. 8°, 36 pp., and map. *Out of print.*

Takes up in some detail Occurrences of Gold, Silver, Lead and Zinc, Copper, Iron, Manganese, Corundum, Granite, Mica, Talc, Pyrophyllite, Graphite, Kaolin, Gem Minerals, Monazite, Tungsten, Building Stones, and Coal in North Carolina.

5. Road Laws of North Carolina, by J. A. Holmes. *Out of print.*

6. The Mining Industry in North Carolina During 1901, by Joseph Hyde Pratt, 1902. 8°, 102 pp. *Out of print.*

Gives a list of Minerals found in North Carolina; describes the Treatment of Sulphuret Gold Ores, giving localities; takes up the Occurrence of Copper in the Virgilina, Gold Hill, and Ore Knob districts; gives Occurrence and Uses of Corundum; a List of Garnets, describing Localities; the Occurrence, Associated Minerals, Uses and Localities of Mica; the Occurrence of North Carolina Feldspar, with Analyses; an extended description of North Carolina Gems and Gem Minerals; Occurrences of Monazite, Barytes, Ocher; describes and gives Occurrences of Graphite and Coal; describes and gives Occurrences of Building Stones, including Limestone; describes and gives Uses for the various forms of clay; and under the head of "Other Economic Minerals," describes and gives Occurrences of Chromite, Asbestos, and Zircon.

7. Mining Industry in North Carolina During 1902, by Joseph Hyde Pratt, 1903. 8°, 27 pp. *Out of print.*

8. **The Mining Industry in North Carolina During 1903, by Joseph Hyde Pratt, 1904. 8°, 74 pp.** ***Out of print.***

Gives description of Mines worked for Gold in 1903; description of Properties worked for Copper during 1903, together with assay of ore from Twin-Edwards Mine; Analyses of Limonite ore from Wilson Mine; the Occurrence of Tin; in some detail the Occurrences of Abrasives, Occurrences of Monazite and Zircon; Occurrences and Varieties of Graphite, giving Methods of Cleaning; Occurrences of Marble and other forms of Limestone; Analyses of Kaolin from Barber Creek, Jackson County, North Carolina.

9. **The Mining Industry in North Carolina During 1904, by Joseph Hyde Pratt, 1905. 8°, 95 pp.** ***Postage 4 cents.***

Gives Mines Producing Gold and Silver during 1903 and 1904 and Sources of the Gold Produced during 1904; describes the mineral Chromite, giving Analyses of Selected Samples of Chromite from Mines in Yancey County; describes Commercial Varieties of Mica, giving the manner in which it occurs in North Carolina, Percentage of Mica in the Dikes, Methods of Mining, Associated Minerals, Localities; Uses; describes the mineral Barytes, giving Method of Cleaning and Preparing Barytes for Market; describes the use of Monazite as used in connection with the Preparation of the Bunsen Burner, and goes into the use of Zircon in connection with the Nernst Lamp, giving a List of the Principal Yttrium Minerals; describes the minerals containing Corundum Gems, Hiddenite and Other Gem Minerals, and gives New Occurrences of these Gems; describes the mineral Graphite and gives new Uses for same.

10. **Oyster Culture in North Carolina, by Robert E. Coker, 1905. 8°, 39 pp.** ***Out of print.***

11. **The Mining Industry in North Carolina During 1905, by Joseph Hyde Pratt, 1906. 8°, 95 pp.** ***Out of print.***

Describes the mineral Cobalt and the principal minerals that contain Cobalt; Corundum Localities; Monazite and Zircon in considerable detail, giving Analyses of Thorianite; describes Tantalum Minerals and gives description of the Tantalum Lamp; gives brief description of Peat Deposits; the manufacture of Sand-lime Brick; Operations of Concentrating Plant in Black Sand Investigations; gives Laws Relating to Mines, Coal Mines, Mining, Mineral Interests in Land, Phosphate Rock, Marl Beds.

12. **Investigations Relative to the Shad Fisheries of North Carolina, by John N. Cobb, 1906. 8°, 74 pp., 8 maps.** ***Postage 6 cents.***

13. **Report of Committee on Fisheries in North Carolina. Compiled by Joseph Hyde Pratt, 1906. 8°, 78 pp.** ***Out of print.***

14. **The Mining Industry in North Carolina During 1906, by Joseph Hyde Pratt, 1907. 8°, 144 pp., 20 pl., and 5 figs.** ***Postage 10 cents.***

Under the head of "Recent Changes in Gold Mining in North Carolina," gives methods of mining, describing Log Washers, Square Sets, Cyanide Plants, etc., and detailed descriptions of Gold Deposits and Mines are given; Copper Deposits of Swain County are described; Mica Deposits of Western North Carolina are described, giving Distribution and General Character, General Geology, Occurrence, Associated Minerals, Mining and treatment of Mica, Origin, together with a description of many of the mines; Monazite is taken up in considerable detail as to Location and Occurrence, Geology, including classes of Rocks, Age, Associations, Weathering, method of Mining and Cleaning, description of Monazite in Original Matrix.

15. **The Mining Industry in North Carolina During 1907, by Joseph Hyde Pratt, 1908. 8°, 176 pp., 13 pl., and 4 figs.** ***Postage 15 cents.***

Takes up in detail the Copper and Gold Hill Copper District; a description of the Uses of Monazite and its Associated Minerals; descriptions of Ruby, Emerald, Beryl, Hiddenite, and Amethyst Localities; a detailed description with Analyses of the Principal Mineral Springs of North Carolina; a description of the Peat Formations in North Carolina, together with a detailed account of the Uses of Peat and the Results of an Experiment Conducted by the United States Geological Survey on Peat from Elizabeth City, North Carolina.

16. **Report of Convention called by Governor R. B. Glenn to Investigate the Fishing Industries in North Carolina, compiled by Joseph Hyde Pratt, State Geologist, 1908. 8°, 45 pp.** ***Out of print.***

17. **Proceedings of Drainage Convention held at New Bern, North Carolina, September 9, 1908. Compiled by Joseph Hyde Pratt, 1908. 8°, 94 pp.** ***Out of print.***

18. Proceedings of Second Annual Drainage Convention held at New Bern, North Carolina, November 11 and 12, 1909, compiled by Joseph Hyde Pratt, and containing North Carolina Drainage Law, 1909. 8°, 50 pp. *Out of print.*

19. Forest Fires in North Carolina During 1909, by J. S. Holmes, Forester, 1910. 8°, 52 pp., 9 pl. *Out of Print.*

20. Wood-using industries of North Carolina, by Roger E. Simmons, under the direction of J. S. Holmes and H. S. Sackett, 1910. 8°, 74 pp., 6 pl. *Out of print.*

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